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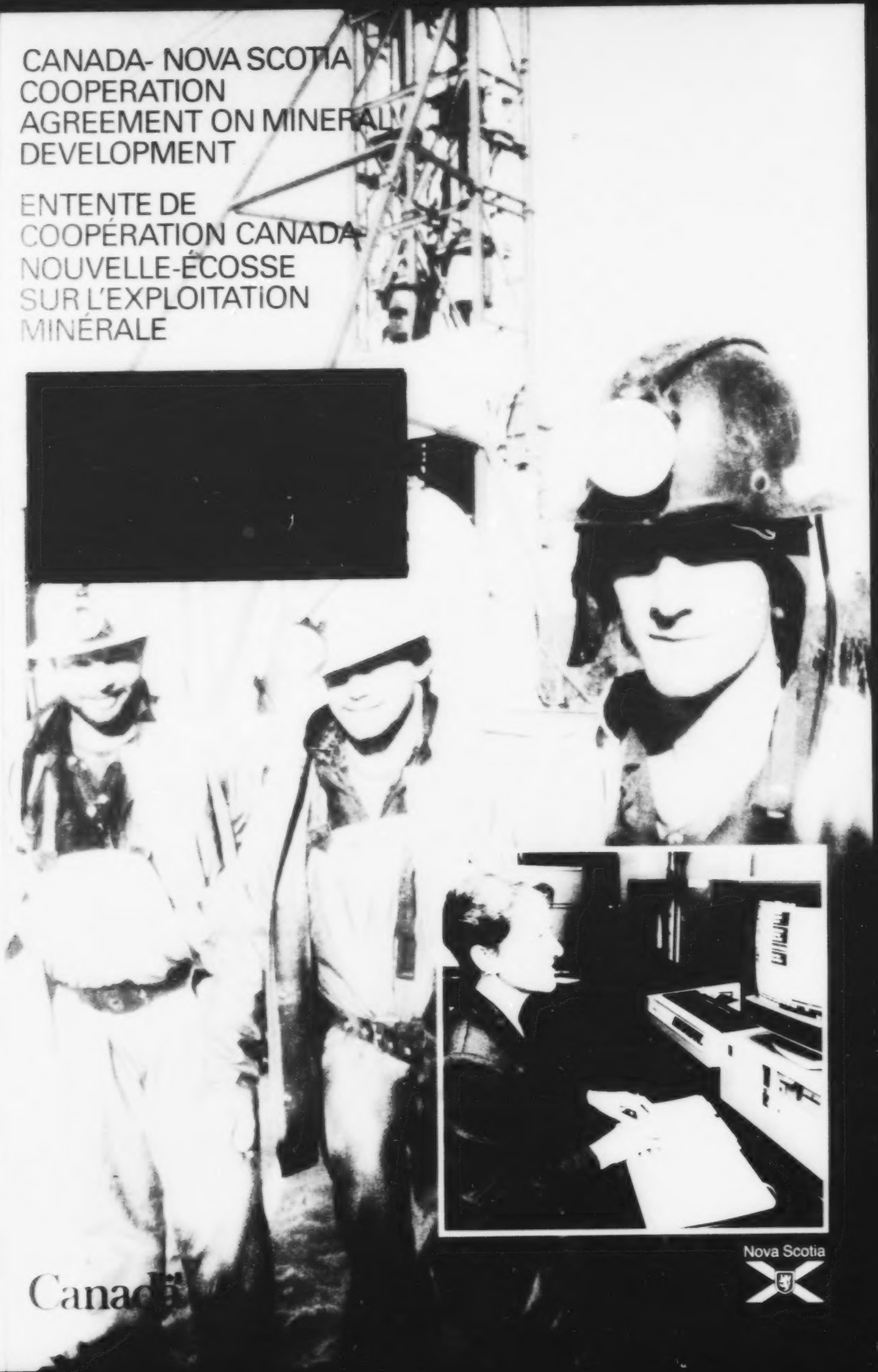

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Nova Scotia

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An Evaluation of Debris Avalanches in the Cape Breton Highlands, Nova Scotia

P. W. Finck

Nova Scotia Department of Natural Resources

Honourable John G. Leefe, Minister

Halifax, Nova Scotia
1992

COOPERATION

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AN EVALUATION OF DEBRIS AVALANCHES IN THE CAPE BRETON HIGHLANDS, NOVA SCOTIA

P. W. Finck

1.0 Introduction

1.1 Purpose and Scope

Debris avalanches (see Glossary, Appendix A) influence present and future land-use in the Cape Breton Highlands. Mineral exploration, mine development, forest harvest practices, fresh water sport fishery and associated tourism could all be effected by this catastrophic process of mass wasting. An understanding of the timing, cause and magnitude of debris avalanche is important for any sustained economic development in this area. Within the Cape Breton Highlands any action which alters the physical environment must be examined to determine its effect on the frequency and/or magnitude of avalanches.

Point source sediment input into streams and rivers from avalanches can dilute or enhance stream sediment geochemical patterns. The effect must be determined if industry and government wishes to correctly interpret the geochemical patterns for exploration purposes. Forest clearing, blasting, stripping, dewatering, et cetera are all actions associated with exploration and mining activity and their effect on the frequency of debris avalanche needs to be examined.

Forest harvest practices must be examined to determine if it effects slope stability. Green belts must be maintained along steep slopes and clearing of such slopes prohibited. Natural variations in the physical environment such as budworm defoliation and climatic change also need to be monitored in order to assess potential effects on slope stability.

Catastrophic input of fine sediment into brooks can smother salmon spawn and alter water quality. Massive input of boulders change the gross characteristics of a river, e.g. turn a gravel bar into a boulder rapid. Depending on the frequency of these events the effect is detrimental to the salmon sport fishery and thus the tourism industry.

The purposes of this report are: (1) Document the present extent of debris avalanches in a selected study area within the Cape Breton Highlands. This will serve as a base line with which to compare any future change in avalanche distribution. (2) Determine historical change in the time verses frequency distribution of debris avalanches. (3) Identify local factors that influence slope stability on a regional or time independent scale. (4) Identify natural or anthropogenic (see Glossary, Appendix A) events that combine with the regional factors and act as triggering mechanisms for the actual avalanche events.

1.2 Study Area And Field Methods

The Cape Breton Highlands was examined from the southern boundary of the Cape Breton Highlands National Park south to Baddeck, excluding the Cheticamp River system. The study area equals

approximately half of the main highland area and is bordered to the west by the Margaree Valley and to the east by Indian Brook (Figure 1).

Field mapping was conducted by the author during the summers of 1991 and 1992. Surficial material exposed along logging roads was mapped at a 1:10 000 scale and compiled on base maps at a 1:25 000 scale. Debris avalanches were initially located by examining 1975 (1:10 000) orthophotographs and 1984 (1:10 000) airphotographs. Additional avalanches were noted and examined while traversing brooks and rivers. Avalanches located in isolated areas were accessed by helicopter. As a final check for old and young avalanches the entire study area was examined by helicopter.

In order to ensure that the sample of avalanches was representative all avalanches within the study area were examined. Two types of wood samples were collected for dating purposes; sections and wedges. Representative sections of wood were cut from the trunks of small trees growing on debris at the base or along the sides of the avalanche chutes. From larger trees a wedge of wood was cut, usually when a scar was being sampled, thus preventing loss of the larger growth. In most cases where samples were collected the life expectancy of the tree was relatively short due to its position along the avalanche channel, continued erosion or wind throw. In the case of small vegetation, sampling simply represented thinning. Samples were cut using a small bow saw. Each sample was numbered individually and its growth position, the part of the tree sampled and its relationship to the avalanche channel and other vegetation carefully noted.

1.3 Physiography And Bedrock Geology

The study area is located within the Northern Tableland of Cape Breton Island as defined by Goldthwait (1924) (Figure 2). The tableland is a planar surface with a gentle southward slope, forming part of a regionally extensive erosional surface or peneplain (see Glossary, Appendix A). The age of this peneplain can be bracketed as pre-Quaternary and post-Carboniferous. There are other numerous peneplains, paleoplains and unconformities (see Glossary, Appendix A) with different suggested ages and elevations within the Atlantic Appalachian Region (Grant, 1989). Grant's regional correlations are poorly constrained and are speculative due to: (1) a lack of overlying dated material and (2) control on post erosional uplift/subsidence.

Hendricks et al. (1992) presented apatite fission track analysis for the Long range Plateau in Newfoundland. This analysis can be interpreted with respect to the "last time" samples passed through the apatite blocking temperature. Fission track length distributions when interpreted with respect to the entire sample history and combined with age versus elevation plots offer the opportunity of constraining cooling, burial and exhumation histories of crystalline rocks. Based on their data Hendricks et al. (1992) concluded that "present relief mimics the Late Palaeozoic topography of the Great Northern Peninsula". "The widely held view that the present-day surface of the Long Range Inlier represents part of a regional Cretaceous peneplain" was not substantiated. Extrapolating these conclusions to the Northern Tableland of Cape Breton Island suggests that the peneplain is a relict Carboniferous feature with stripping of Late Palaeozoic cover during the Early Mesozoic as suggested by Hendricks et al. (1992).

The Cape Breton Highlands are composed predominantly of Late Precambrian - Middle Palaeozoic crystalline rocks (Figure 3). Predominant lithologies in the northwestern Cape Breton Highlands are volcanic rocks, volcanogenic sedimentary rocks and their metamorphic equivalents. The central and eastern Highlands are composed mainly of granite to dioritic plutonic rocks, tonalite and lesser gneiss. The western end of the central and eastern Highlands is composed of metasedimentary rocks. North to northeast structural trends in the bedrock are defined by foliation, brittle faults and ductile shears.

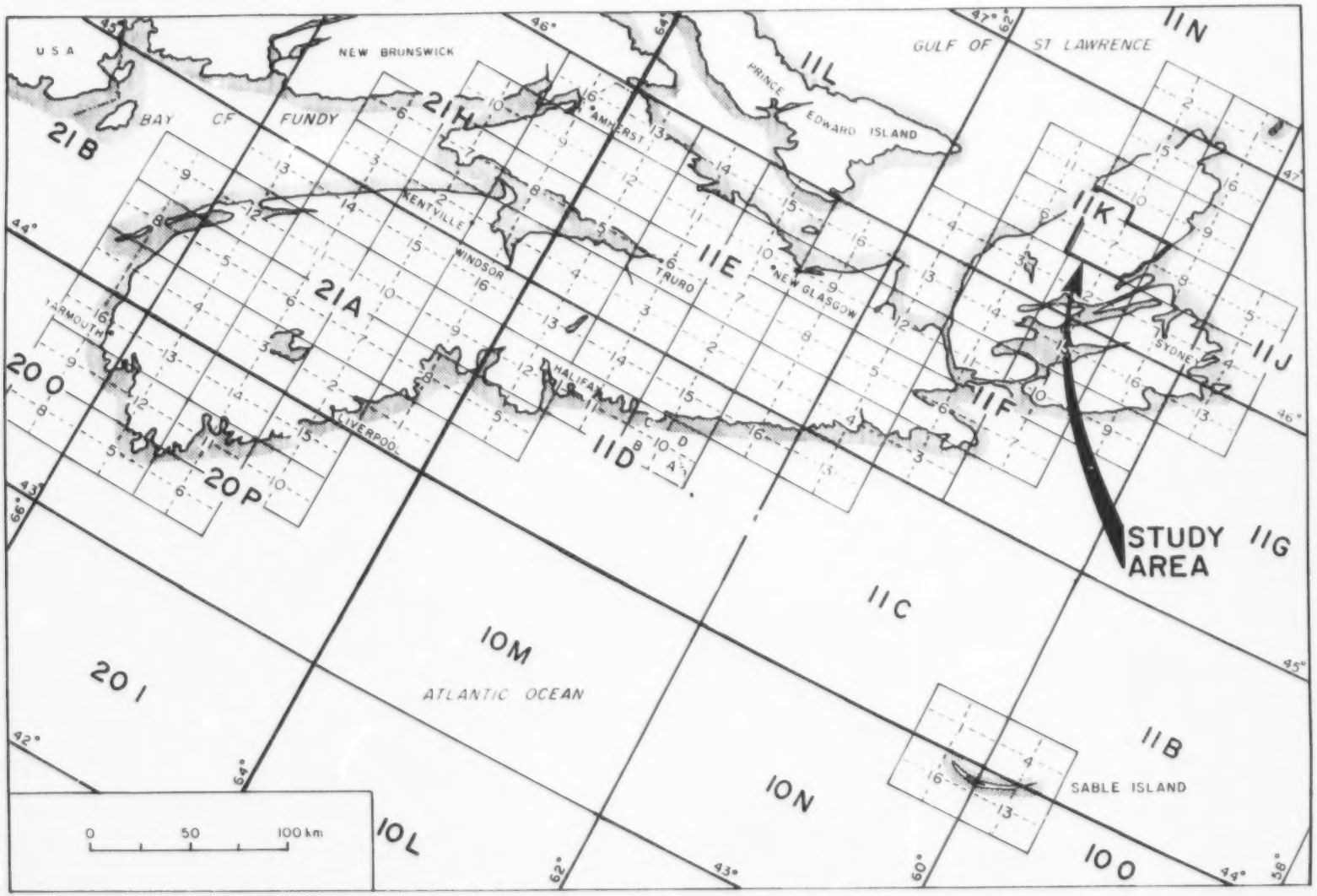


Figure 1. Location of study area.

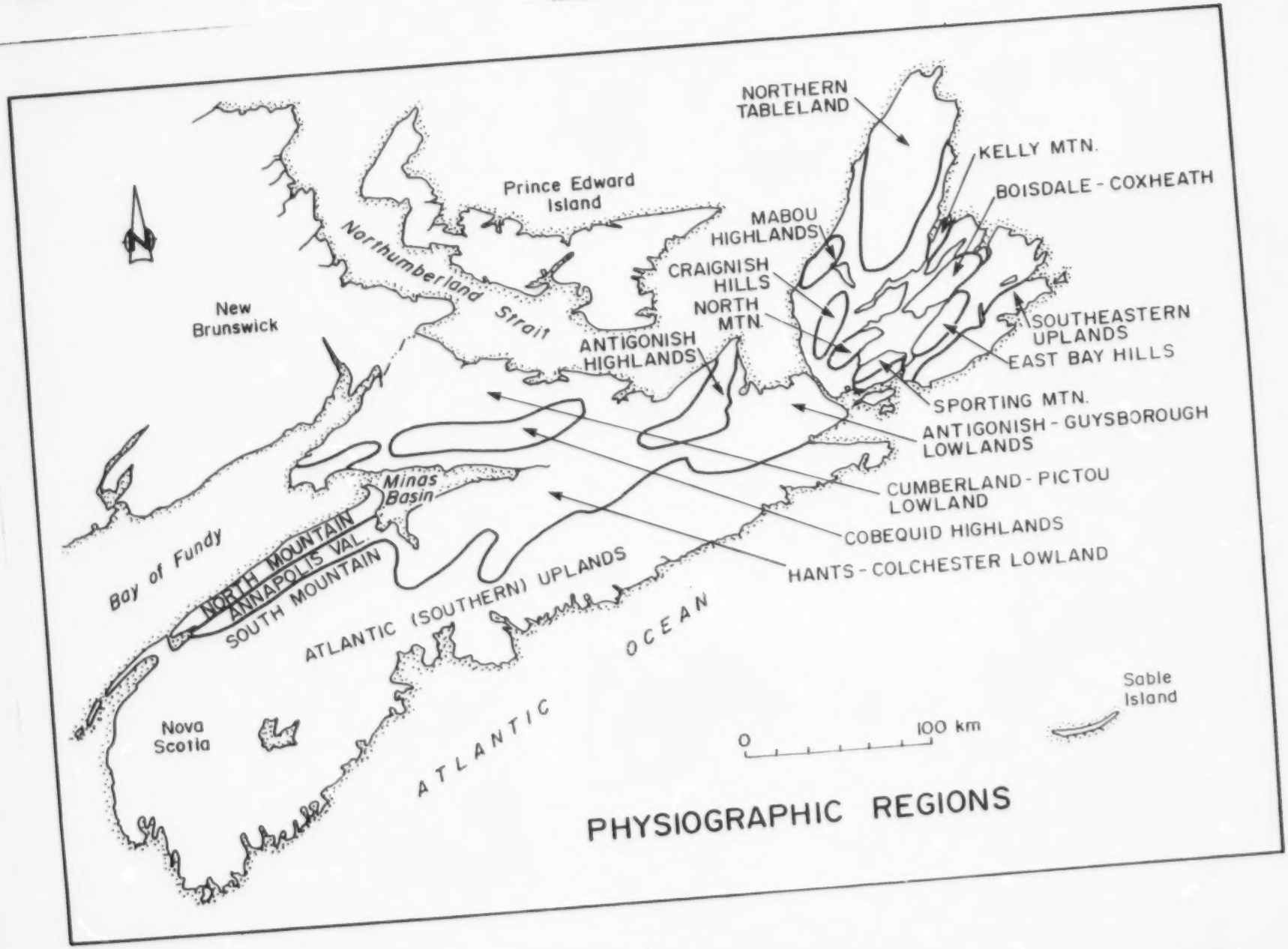


Figure 2. Physiography of Nova Scotia as shown by Goldthwait (1924).

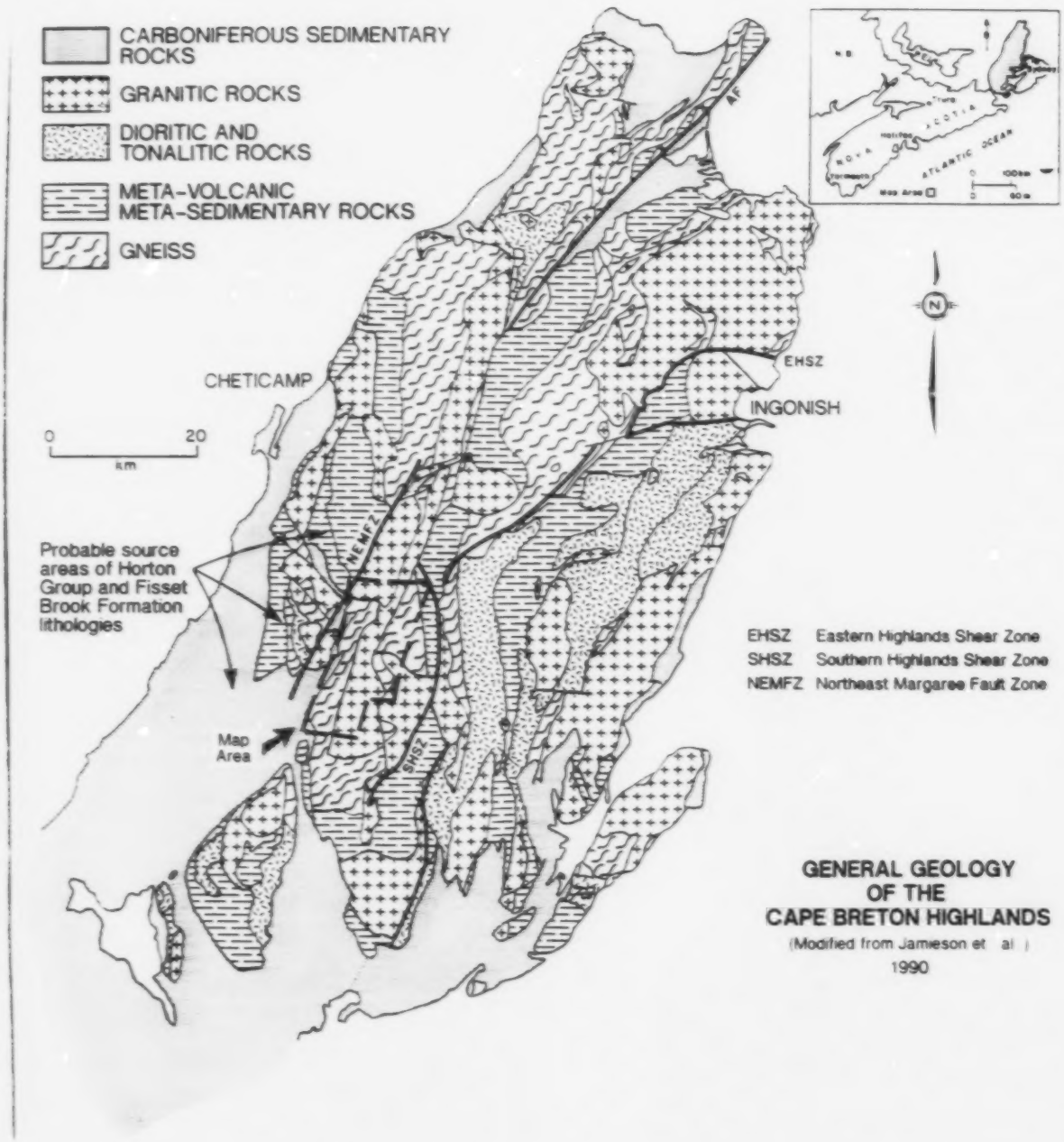


Figure 3. Regional geology map of Northern Cape Breton Island (after Jamieson, et al., 1990).

2.0 Quaternary Geology

2.1 Introduction

Detailed descriptions of glacial and residual materials from Finck (1992) are summarized in section 2.3 and are applicable to similar materials observed throughout the present study area. The observations were consistent with regional Quaternary mapping by Grant (1988), map 1631A. In the west-central portion of the present study area Finck (1992) identified 7 debris avalanches. An avalanche on Nile Brook, first noted by Milligan (1970), is a dual avalanche with a younger (1975 - 1984) avalanche channel coalescing with a pre-1966(67) avalanche channel. The other 5 avalanches occurred in the time period between June, 1975 and August, 1984. No other study specifically examines the distribution, causes and effects of debris avalanches in the Cape Breton Highlands.

Ice flow history for Cape Breton was summarized by Grant (1971, 1976). In northern Cape Breton regional ice flow was southeastward while in southwestern Cape Breton the flow was more easterly. Flow patterns reversed during late Wisconsinan phases flowing towards the northwest, north and northeast from an ice centre located on the then emergent continental shelf. Final ice flow was restricted to local ice caps centred along the axis of the northern plateau with ice flow mainly towards the east, west and southwest.

Glacial erosion has not modified the well developed dendritic drainage pattern of streams within the study area, evidenced by the V-shaped stream valleys rather than the classic U-shaped glaciated valleys. In the western part of the study area a lack glacial erosion and the preponderance of weathered bedrock limits the preservation of and/or the formation of small scale glacial erosional features. However in the southeast part of the study area east-southeast trending striations are common.

Surficial materials within the study can be used as indicators of subglacial conditions. The preservation of grus and saprolite suggest that glacial ice was locally non erosive and was therefore frozen to its bed, cold based or stagnant. However, the presence of glaciotectonic features (see Glossary, Appendix A) described by Finck (1992) indicates that glaciers were locally warm based and active. The deposition of allochthonous till (see Glossary, Appendix A) and the formation of striations indicates that subglacial conditions alternated between deposition and erosion.

2.2 Stratigraphy

Figure 4 from Finck (1992) is a schematic representation of the stratigraphic relationships between the major surficial units mapped in the study area. The aerial distribution of these materials is shown in Figure 5. Saprolite (see Glossary, Appendix A) is considered to be the oldest surficial material in the study area with a minimum pre-Wisconsinan age (>120 000 years) and probably a pre-Quaternary age (Finck, 1992). Grus (see Glossary, Appendix A) is a weathering continuum of the saprolite and as such is coeval. Both allochthonous and autochthonous tills (see Glossary, Appendix A) found in the Cape Breton Highlands are believed to be Wisconsinan in age. This is based on their fresh appearance, apparent east-southeast direction of transport and the regional occurrence of such tills overlying interglacial organics believed to be of Sangamon age (Stea, et al., in press; Grant, 1989). Relationships between felsenmeer (see Glossary, Appendix A) and the other surficial materials are uncertain. Felsenmeer may be both preglacial and post glacial in age. Colluvium (see Glossary, Appendix A) is deposited as part of a continuum spanning the entire Holocene. Preglacial colluvial deposits are probably present but buried in valleys by glacial, glaciofluvial or other younger colluvial materials.

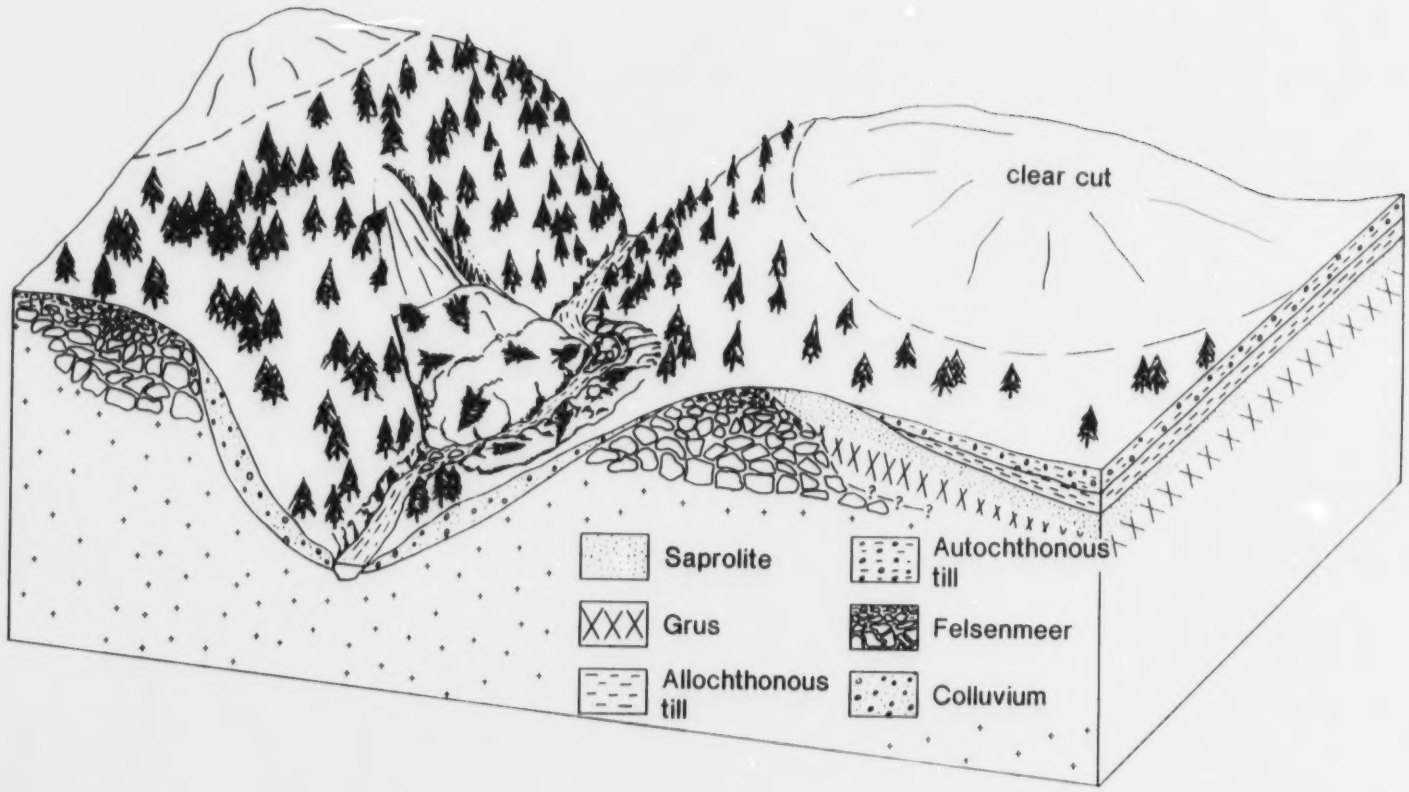


Figure 4. Cartoon showing stratigraphic relationships between surficial materials and avalanches (after Finck, 1992).

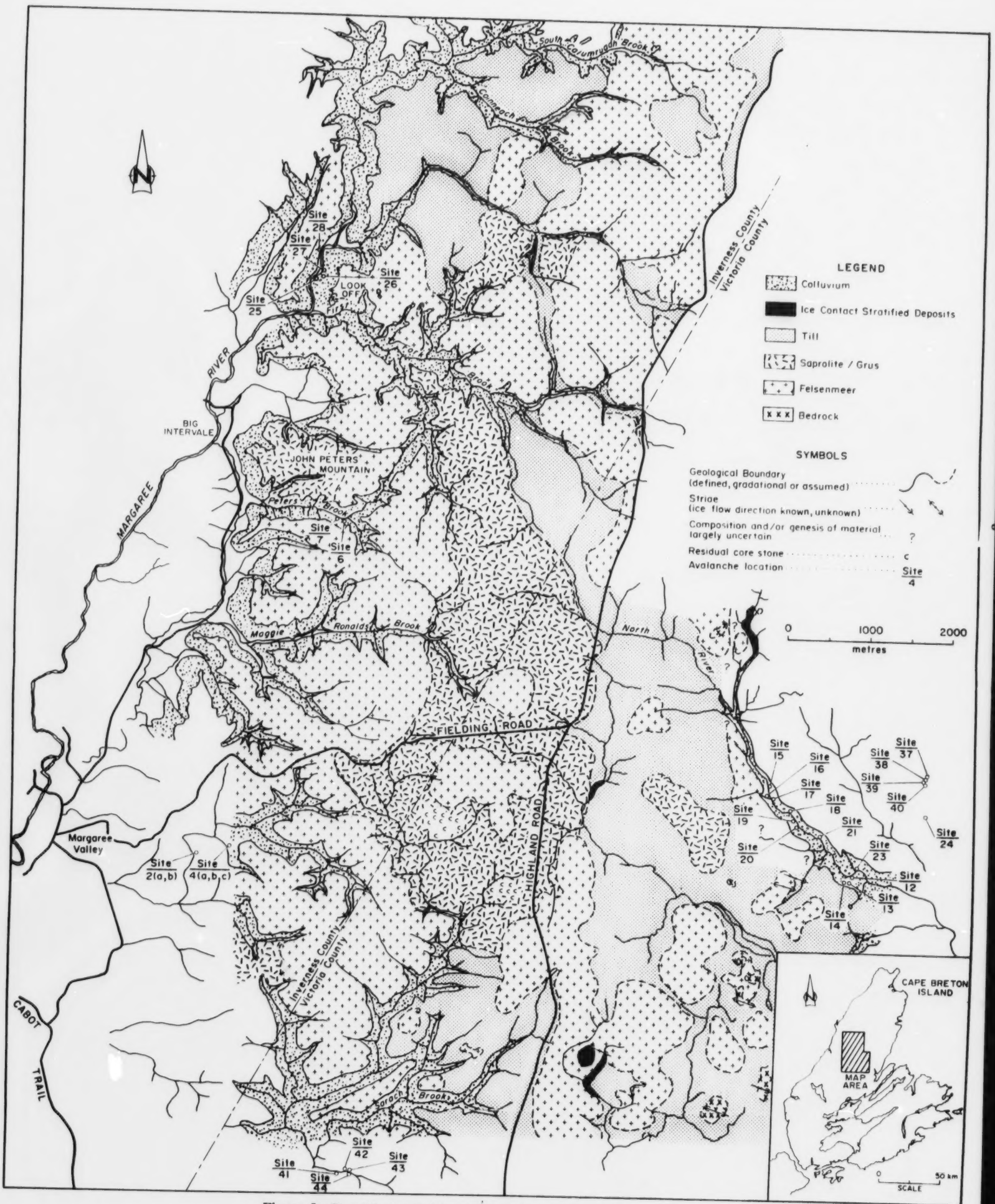


Figure 5. Simplified surficial geology of the study area (also striations).

2.3 Surficial Units

Saprolite is exposed in the study area as 1 - 2 m thick gutter cuts. It is soft, easily excavated with a shovel and maintains a steep slope angle due to its high clay content. Primary gneissic and hypidiomorphic granular texture of the parent bedrock is preserved. At many exposures there appears to be a weathering continuum between grus and saprolite. A vertical colour zonation typically exists from red and yellow at the top of the saprolite to greys, browns and greens at the base. In saprolite, feldspar and biotite weather to poorly crystalline kaolinite, gibbsite, and a minor component of iron oxide (McKeague, et al., 1982).

Grus is often massive and fresh appearing with the superficial appearance of the parent bedrock. Upon excavation the grus disintegrates into pebble to sand sized crystal fragments. Crystal fragments from the original granitic material (e.g., plagioclase) weather to gibbsite and kaolinite (Velbel, 1987). Grus contains rounded boulders or core-stones that are remnant, rounded fragments of the bedrock that remained insitu as weathering preferentially penetrated along joint systems in the parent bedrock.

Both allochthonous and autochthonous till occur in the study area. Autochthonous till has a appearance similar to that of grus. The clasts are weathered crystal fragments and highly angular rock debris in a dirty-brown, sandy, compact matrix. The autochthonous till is wide spread in the western part of the study area (Figure 5). The allochthonous till is reddish-brown, clast poor with a silty matrix. Clasts reflect local bedrock geology as well as source areas to the west-northwest in the Horton Group and Fisset Brook Formation (Figure 3). This till is more prevalent in the central to southeast part of the study area (Figure 5).

Felsenmeer occurs as highly angular shattered fragments of in-situ bedrock and can be used to accurately map bedrock geology. Colour variations in the felsenmeer reflect colour and/or lithological variations in the underlying parent bedrock. Quartz veins and leucocratic/mafic variations in gneissic bedrock is like wise expressed in the felsenmeer.

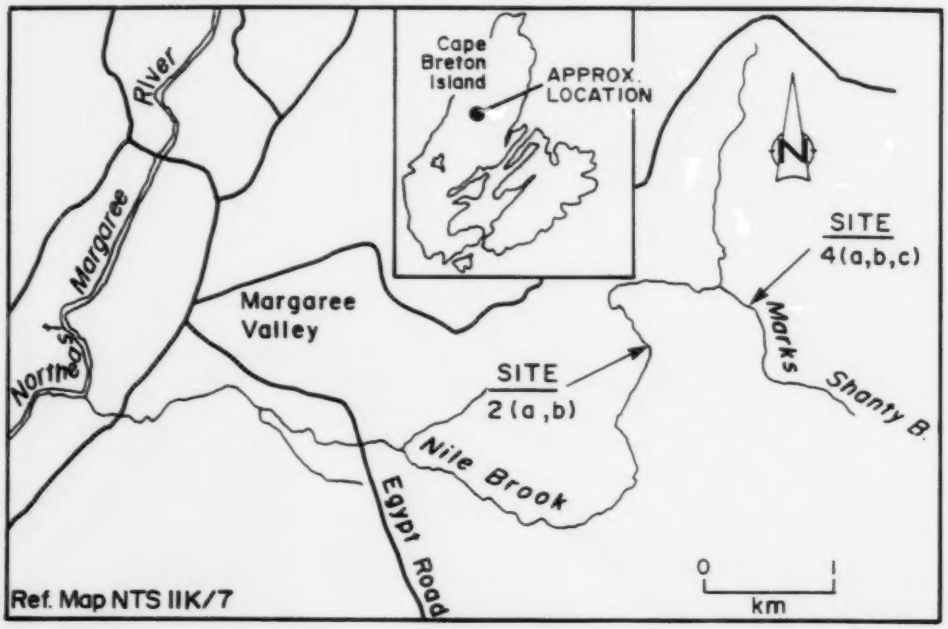
A gravel pit at the base of the Fielding Road is excavated in colluvial material. The colluvium exhibits typical alternating layers of shattered rock, weathered residual material and diamicton. Colluvium was mapped on the walls of stream valleys draining the interior of the tableland using airphotographs and the relation of slope angle to mass wasting.

3.0 Field Observations

49 avalanche sites (55 avalanche events) were surveyed between June and August, 1991. The avalanches occur in clusters within 5 catchment basins that are dispersed regionally across the study area (Figures 6a - 6d). Field observations at each avalanche site are presented in Appendix B and C. The following sections briefly summarize these general observations.

3.1 Bedrock Geology, Slope Angle And Structure

The avalanches occur on slopes cut in granitic rocks. Granitic rocks are more competent than other sedimentary and metamorphic rocks (e.g. mudstone, slate), due to a relative lack of planes of weakness such as bedding and cleavage. This increases the slope of the valley walls and results in over-steepened critical slopes.



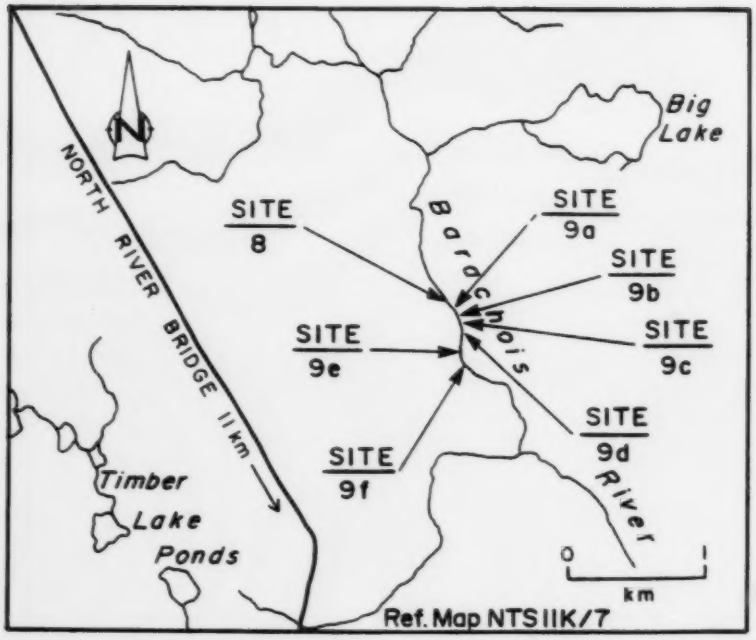


Figure 6a. Avalanche location maps.

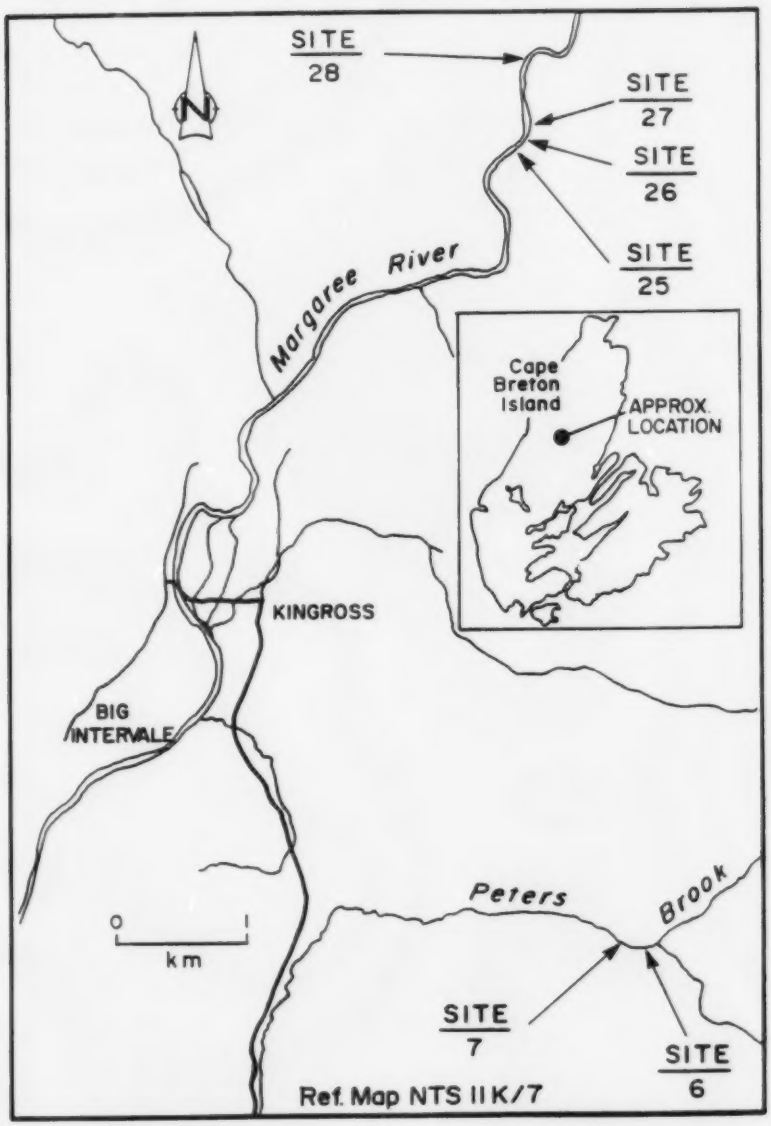
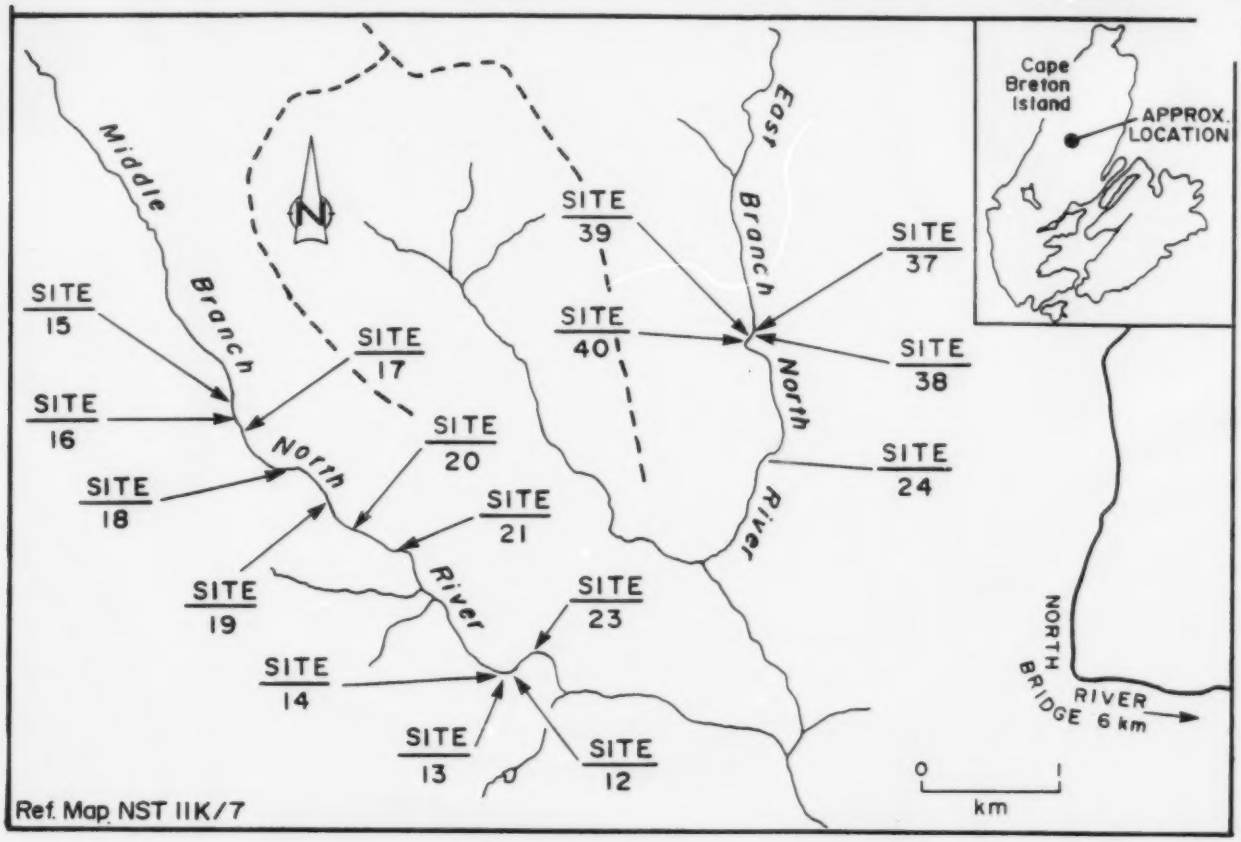


Figure 6b. Avalanche location maps.



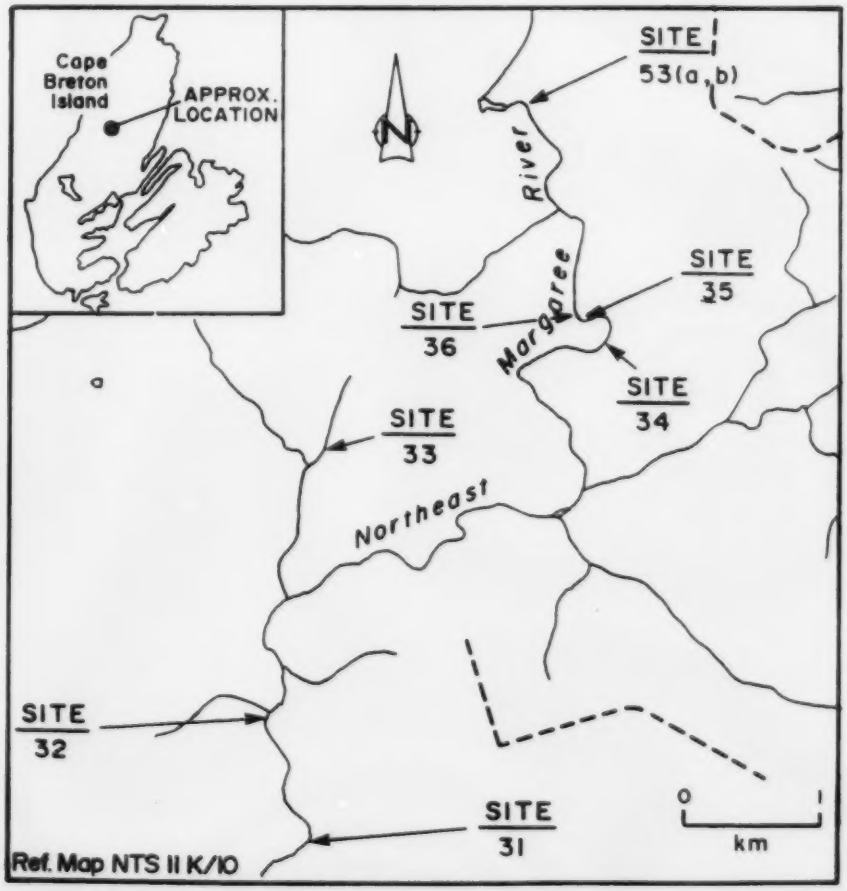
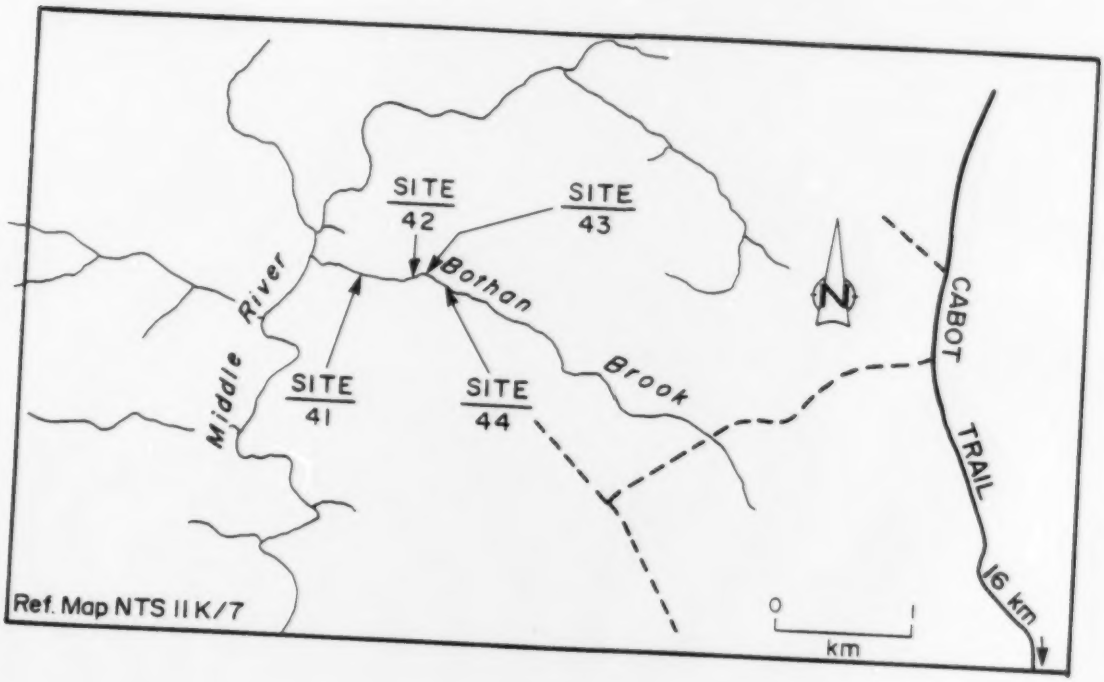


Figure 6c. Avalanche location maps.



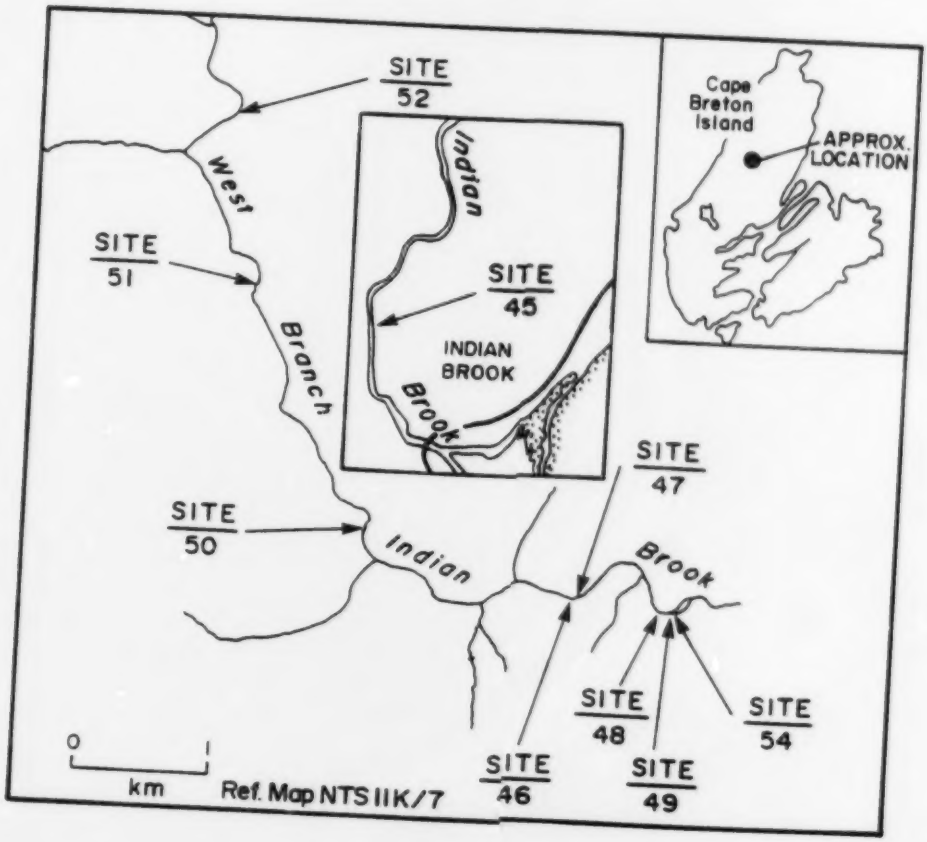


Figure 6d. Avalanche location maps.

Figure 7 is a plot of avalanche original slope angles vs residual slope angles (see Glossary, Appendix A). The average original slope angle is 40 degrees vs an average residual slope angle of 42 degrees. Slope angle generally remains the same or increases following avalanche. Where the slope angle remains the same erosion is shallow in the avalanche chute. Where slope angle increases erosion in the avalanche chute is shallow at the top increasing towards the base. This is due to incision of thick colluviated debris at the base of the slope and/or debris loading of the slope base followed by bedrock collapse.

Joints decreases the stability of a slope. Within the study area the average dip of major joint sets associated with avalanches is 60 degrees. If the joints dip away, normal or towards a slope the result is a situation of decreasing stability when coupled with the steep dip angles (Cooke and Doornkamp, pg. 120; 1990).

3.2 Slope Material, Debris Volume And Stream Sediment Input

88% of the avalanches have slope material composed of shattered rock and/or colluvium while 12% of the avalanches have slope material composed of till. When the slope material is shattered rock and/or colluvium an average of 2400 m3 of debris per avalanche was translocated. When the slope material is till an average of 3800 m3 of debris was translocated by each avalanche. Avalanches with slopes composed of or veneered by till account for a disproportionate 18% of the total volume while accounting for only 12% of the avalanches.

In excess of 127,000 cubic metres of debris was translocated by the avalanches identified in this study. Approximately 100, 000 m3 of the debris was input catastrophically or over a several year period into the five catchment basins. Approximately 27, 000 cubic metres of debris was translocated by avalanches that did not initially impact into the rivers. Rain and melt water subsequently utilized the avalanche chutes as spillways and input some of this debris into the rivers. Avalanche length, width and depth figures are estimates so volume figures are subject to large error. The author feels that the actual debris volumes are significantly larger than those reported.

Of 49 avalanche sites examined 14 input debris into rivers in a catastrophic manner, 24 in both a initial catastrophic and a later annual manner and 7 in mainly an annual manner following an initial failure. Debris avalanches can cross and completely dam rivers, e.g. debris from avalanche #25 crossed the 38 m wide Margaree River and impacted into trees on the opposite bank. This avalanche represents in excess of 24,000 cubic metres of debris and dammed the river to a height of several metres for a short period of time . Other avalanches such as 2a (Nile Brook, 10,000 cubic metres), 4a (Mark Shanty Brook, >4000 cubic metres), and several other avalanches completely blocked their respective rivers. In addition other avalanches blocked varying percentages of their rivers (Appendix C). Debris avalanches can attain velocities of 10 to 100 m/sec (Cooke and Doornkamp, pg. 110-111; 1990).

3.3 Points Of Failure

The location of initial failure could not be determined with certainty for 18 of the 49 avalanche sites. In the majority of cases slippage between weathered material and underlying more competent bedrock on the middle and upper slopes is the point of failure. Rock topple on the upper slope near the intersection of the valley wall and the peneplain with resultant loading of the middle slope was also a major failure mechanism. Failure on the middle and upper slopes is demonstrated by the occurrence of 7 failed avalanches where the debris stopped before it reached the river (later secondary sliding and water channelling input debris into the river in some cases).

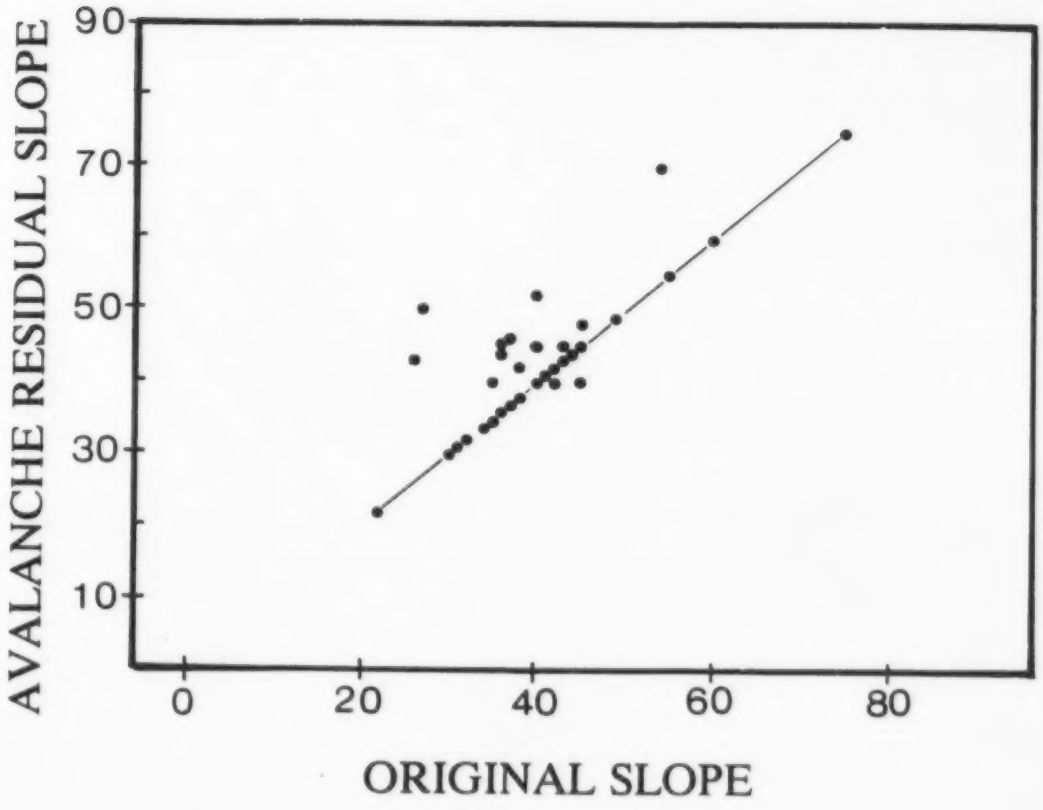


Figure 7. Avalanche original slope angle verses residual slope angle.

Bank undercutting is considered the primary cause of failure for only 3 avalanches, illustrating the stability of river banks in the study area; even with the high slope angles valley walls are stable. Without an avalanche triggering mechanism long term mass wasting (creep) is in balance or exceeds lateral slope retreat. At avalanche #25 on the Margaree River the avalanche chute cuts through a thick lens of bouldery diamicton. At this site creep is sufficient to maintain a supply of weathered material to the base of the slope, in balance with the rate of lateral river erosion. Elsewhere (e.g. north branch of First Forks Brook) river down cutting is proceeding much faster than slope retreat. Vertical walls several metres apart are common (Horne, pers. comm., 1992). However the upper slopes are stable (at least in the short term) and the rock walls composed of coherent granitic rock are also stable.

3.4 Vegetation

Crown Land Forestry Series maps produced by the Nova Scotia Department of Lands and Forests (1970) classify tree cover within the study area as Softwood (S; up to 25% hardwood); Mixedwood (M; 26% to 75% hardwood) and Hardwood (H; greater than 75% hardwood). 45% of the avalanches occur in areas designated as softwood, 38% in areas of mixedwood and 17% in areas of hardwood. Within the mixedwood classification softwood percentages are usually much greater than that of hardwood percentages (Appendix C). The percentage of dead softwood (killed by spruce budworm) varies from 35% to 90% (Plate 1).

Trees carried down slope by the avalanche debris were often trapped in the debris fan at the base of the avalanche. These trees were predominantly highly decomposed softwood which was over represented in the debris fan as compared with the visual estimate of the slope vegetation. For example at avalanche #12 the slope vegetation was mixed softwood/hardwood yet trees buried in the debris fan were 100% decomposed softwood (Appendix C).

4.0 Avalanche Classification

4.1 Introduction

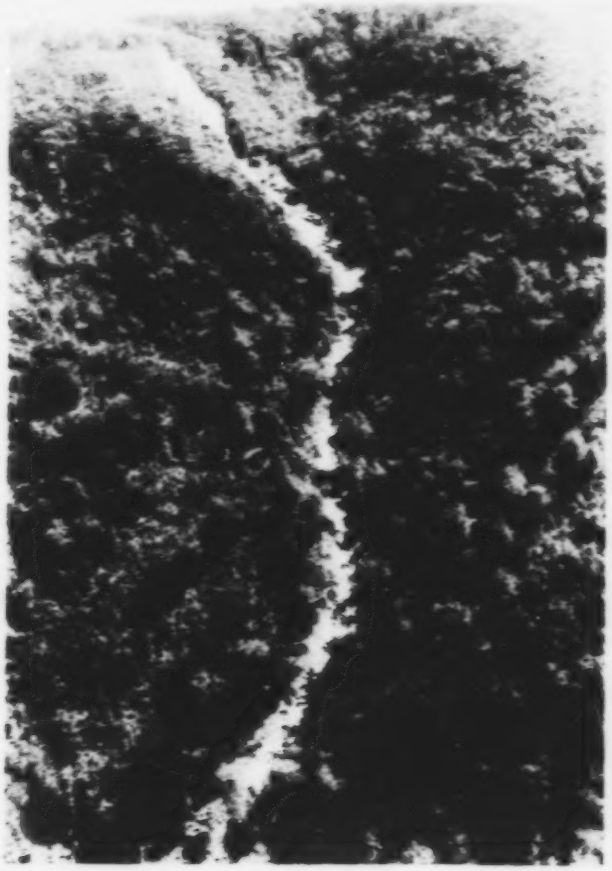
Field observations indicate that avalanches in the Cape Breton Highlands can be divided into four shape classifications. These classifications (Figures 8 - 12) reflect variations in primary valley features such as slope morphology, height, slope material, debris volume, etc. This is not a new concept and has received considerable attention in landslide literature. Nicoletti and Sorriso-valvo (1991) examined geomorphic controls on the shape and mobility of rock avalanches. They concluded that local morphology controls the shape and motion of landslides by: (1) channelling the debris mass, (2) allowing unobstructed spreading of the debris mass, and (3) by impact against an opposite slope. Nicoletti and Sorrisso-valvo (1991) further concluded that morphology controls the rate at which total mechanical energy is dissipated and described three types of geomorphic control; low-energy, moderate-energy and high-energy-dissipative, ie high-mobility, intermediate-mobility and low-mobility avalanches. Nicoletti and Sorrisso-valvo (1991) excluded all rock avalanches with volumes less than 5,000,000 cubic metres because they were uncertain that mobility is particularly pronounced below this threshold.

The classification of high-mobility and intermediate-mobility avalanches is applicable to the small volume debris avalanches examined in this report. Though the largest avalanche examined (25, 000 cubic metres of debris) is small compared to avalanches studied by Nicoletti and Sorrisso-valvo (1991), a high degree of mobility is demonstrated by the run-out of debris and the scaring of trees along the sides of the avalanche channels (refer to sections 3.2 and 5.2).

Plate 1. Site 18. Middle Branch North River. Dead softwood dominate valley-slope along edge of debris avalanche chute.

Plate 2. Site 48. West Branch Indian Brook. Stony-bouldery till with a sandy matrix deposited as a terrace along the upper-valley wall.

Plate 3. Site 25. View of Margaree Valley avalanche.



4.2 Classification

Figures 8 - 12 illustrate the 4 divisions and 2 subdivisions of avalanches observed within the study area. These diagrams are schematic and incorporate features observed at several different sites. As such any single avalanche will not show all features included in the representative morphologic model.

4.2.1 Low-mobility avalanches - inverted-cone-shape - class 1

Figure 8 illustrates the important geomorphologic features associated with small inverted-cone shaped avalanches mapped in this study. Field observations and avalanche site specific classification are presented in Appendix B and C. The low-mobility (high-energy-dissipative control) avalanche classification of Nicoletti and Sorriso-valvo (1991) is least applicable to the inverted-cone shaped avalanches observed in this study. In this case the actual mobility of the debris is small and stoppage is controlled by (the energy is dissipated) by the river rather than the opposite slope. These landslides are usually characterized by a combination of bank undercutting followed by rotational slump.

Class 1 avalanches occur either immediately below the final break in slope directly above the river or immediately above this break in slope. The distance between a class 1 avalanche and the intersection of the valley wall and the peneplain surface is several hundred metres, depending on the height of the valley wall. These avalanches occur on bends in the river where undercutting is a trigger mechanism in conjunction with other factors that will be discussed in later sections. When these avalanches occur in colluviated diamicton slope wash is channelled toward the chute resulting in formation of a channel that erodes up slope through the unconsolidated sediment. Thus sediment input is initially catastrophic (though small in volume) followed by annual input of sediment during runoff from rain or melting snow.

Figure 13 illustrates the volume distribution of avalanches with respect to their morphologic classification. Overlap exists between the different morphologic classes, however a clear relationship between morphologic class and debris volume is apparent, increasing in the order 1-2a-3-2b-4. The exception is class 2b; the reason for which will be discussed in section 4.2.2. Class 1, inverted-cone-shaped avalanches are characterized by a low debris volume (average = 210 cubic metres; Table 1).

4.2.2 Intermediate-mobility avalanche - tongue-shape - class 2a and 2b

Nicoletti and Sorriso-valvo (1991) described tongue-shaped rock avalanches that "free from lateral constraints... spread laterally while streaming downslope, stopping spontaneously when it comes to a wide valley or plain... long straight dip-slopes... favour such a situation". Class 2a avalanches fit this description in that they commonly occur along sections of valley wall where debris is not markedly channelized by the valley wall. The avalanche is free to spread laterally as shown in Figure 9.

Class 2a avalanches straddle the upper, middle and lower slopes on the valley walls. The distance between a Class 2a avalanche and the peneplain surface is variable. In low valleys the headwall of the avalanche almost intersects the peneplain. Where the valley is deep the distance is several hundred metres (in this case the avalanche does not intersect the upper steep slope). The surface of failure in Class 2a avalanches is the weathered, colluviated debris - bedrock interface. Initial sliding occurs on the middle to upper slope depending on the influence of rock topple near the head wall. Avalanche debris stops when it spreads fan-like into the river. Energy of the avalanching debris is only sufficient to partially dam the river.

Class 2a avalanches are the most common avalanche within the study area. They are relatively small (volumetrically) with average debris volumes of 700 cubic metres per event (Table 1 and Figure 13)

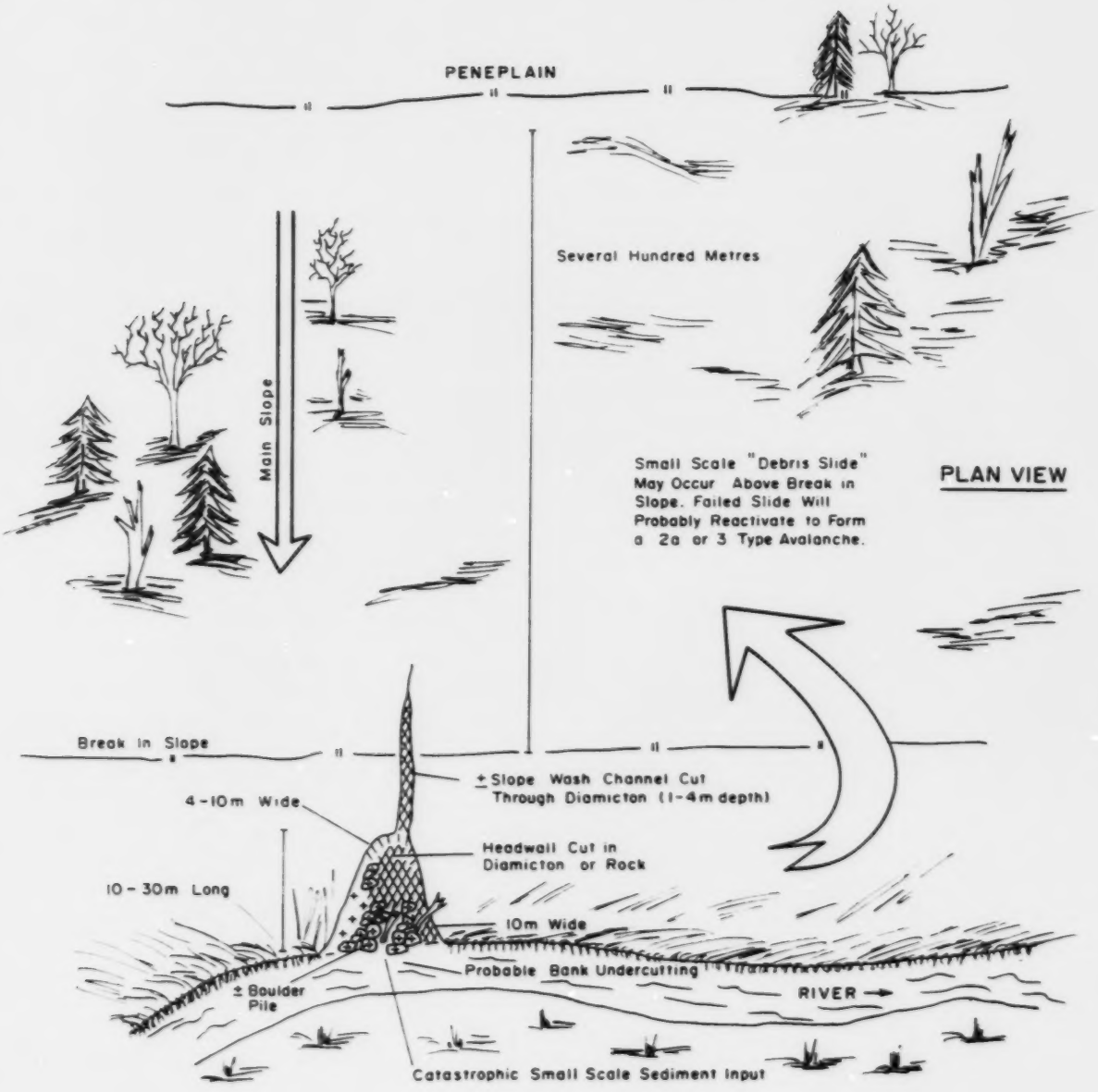

PENEPLAIN
Several Hundred Metres
Main Slope
Small Scale "Debris Slide" May Occur Above Break in Slope. Failed Slide Will Probably Reactivate to Form a 2a or 3 Type Avalanche.
PLAN VIEW
Break in Slope
± Slope Wash Channel Cut Through Diamicton (1-4m depth)
4-10m Wide
Headwall Cut in Diamicton or Rock
10-30m Long
10m Wide
Probable Bank Undercutting
RIVER
± Boulder Pile
Catastrophic Small Scale Sediment Input

Figure 8. Low-mobility avalanche - class 1.

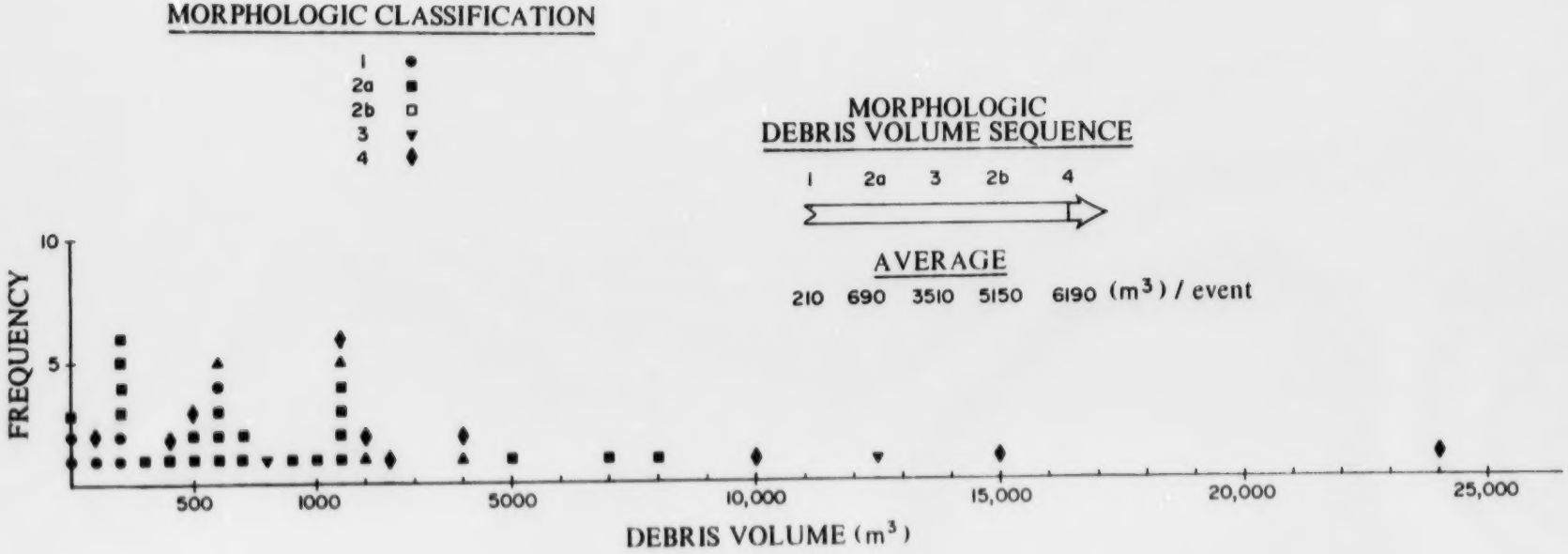


Figure 13. Avalanche frequency verses volume (keyed to morphologic classification).

Table 1. Average volume of avalanche debris generated by each morphologic avalanche class.

Morphologic Classification	Number of Avalanches	Average Volume of Debris $(m)^3$	Minimum $(m)^3$	Maximum $(m)^3$
1	7	210	9	1300
2a	17	700	24	1600
2b	4	5150	1000	8000
3	6	3500	680	12400
4	10	6200	140	24000

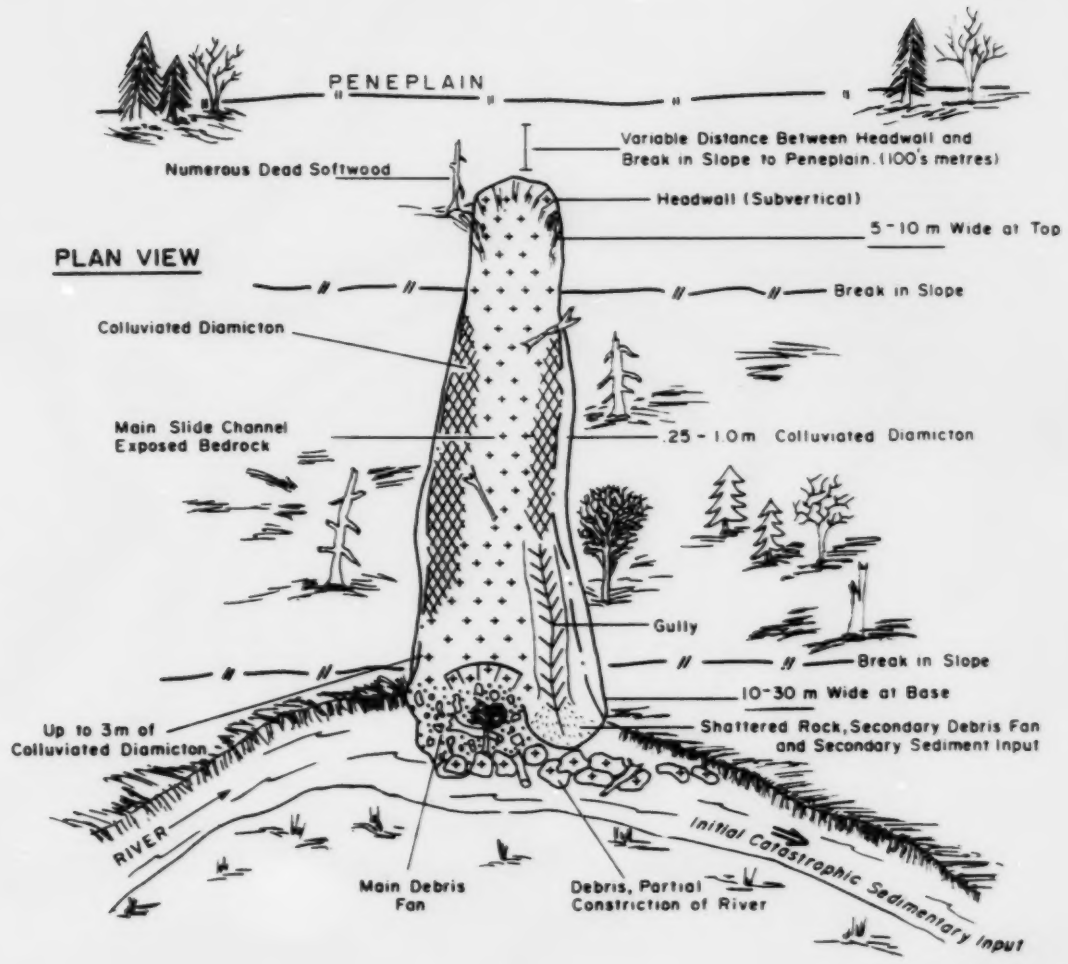


Figure 9. Intermediate-mobility avalanche - class 2a.

though some may reach volumes of 1600 cubic metres (Appendix B). Class 2a avalanches input relatively small volumes of sediment catastrophically into a river. However due to their frequency this effect is cumulative. In addition the debris fans and water running down the avalanche chutes serve as sources of annual sediment input (Appendix C).

Class 2b avalanches are a "special case". Valley wall or slope characteristics of Class 2b avalanches are the same as that of class 2a avalanches. However in this case (Figure 10) the slope material is till. The Indian Brook catchment basin is the only area that contains Class 2b avalanches. Along Indian Brook a stony to bouldery till with a sandy matrix mantles the valley walls (Figure 10, Plate 2). Initial sediment input into Indian Brook is catastrophic, however once exposed this easily eroded till serves as a annual sediment source for the river. Sediment is eroded from the walls and base of the avalanche and washes down the avalanche chute into the river. Due to its relative fine grained nature the material is quickly assimilated by the river system. This process is expected to be pronounced in the spring when frost thaw has created particularly unstable conditions coupled with rain, snow melt and high river discharge.

Till, as the predominant slope material is unique to Class 2b avalanches and controls both the volume of sediment input into rivers and also the mode of input, ie the general absence of relatively stable debris fans. Class 2b avalanches produce an average of 5150 cubic metres of debris per avalanche site (Table 1). Shape of the avalanches are controlled by the absence or presence of competent bedrock at the base of the valley wall (Figure 10, see section).

4.2.3 Intermediate- to high-mobility avalanche - failed-ribbon-shaped - class 3

Class 3 avalanches straddle the upper- and middle-slopes of valley-walls where there is a distinct change in gradient between the upper- and middle-slope area, e.g. avalanche sites 13 and 14 (North River). Avalanches extend to the lower slopes where this change in gradient is not pronounced, e.g. avalanche site 21 (North River). Slope morphology initially channelises and contains the debris masses in the upper slope of a Class 3 avalanche. However in the middle- to lower-slope region the debris mass spreads prior to entering the river. This results in a loss of energy sufficient for obstructing vegetation (typically large, well rooted hardwoods) to block and halt the debris. The headwall of Class 3 avalanches approaches the break in slope with the regional peneplain (Figure 11). Recent debris at the base of an otherwise "older avalanche" suggests that the avalanche may work backwards eroding up-slope. This is due to removal of supporting rock, vegetation, etc in the headwall area. Initial failure is in the middle- to upper-slope area at the interface between colluviated, bouldery diamicton and more competent underlying bedrock.

Class 3 or failed ribbon-shaped avalanches produce an average of 3500 cubic metres of debris per event, however the volumes are highly variable ranging from 680 to 12,400 cubic metres (Table 1). Debris from Class 3 avalanches is not input catastrophically into rivers (Appendix C) except for minor input at avalanche site 31. In general debris is either retained on an intermediate slope or input (partially input) on an annual basis by rain and meltwater funnelling down the avalanche chute (Figure 11). Class 3 avalanches may reactivate resulting in the formation of a Class 4 avalanche.

4.2.4 High-mobility avalanche - ribbon-shaped - class 4

Nicoletti and Sorriso-valvo (1991) describe avalanches where the "detachment zone is approximately amphitheatre shaped and there is a narrow valley down which the debris is channelized". Class 4 avalanches fit this description in that they are highly mobile (refer to section 4.1). In addition debris is channelized, not by a narrow valley, but by local undulations and curvatures (concave) or oblique obstructing slopes in the valley walls (Figure 12 and Plate 3). In contrast with Nicoletti and Sorriso

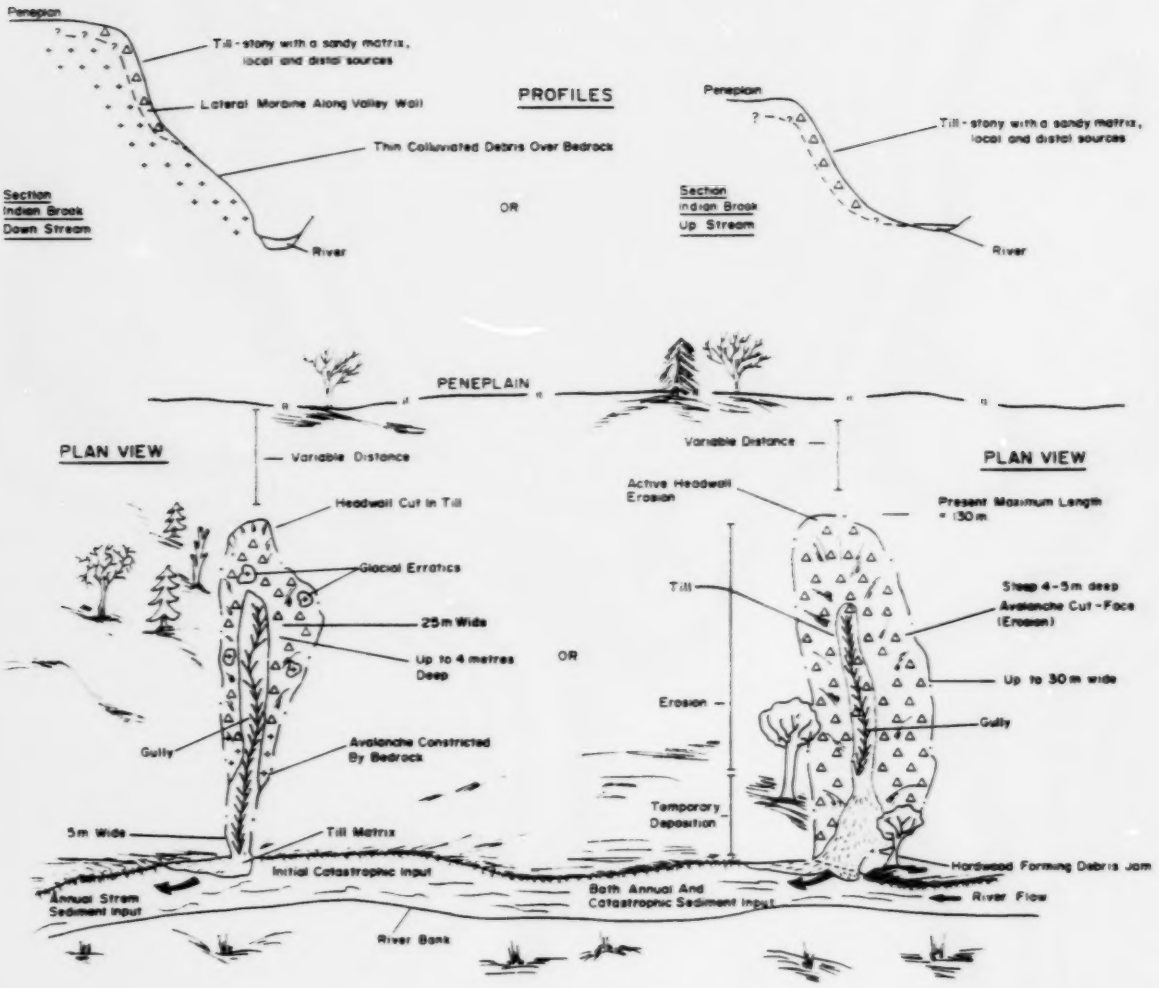


Figure 10. Intermediate-mobility avalanche - class 2b.

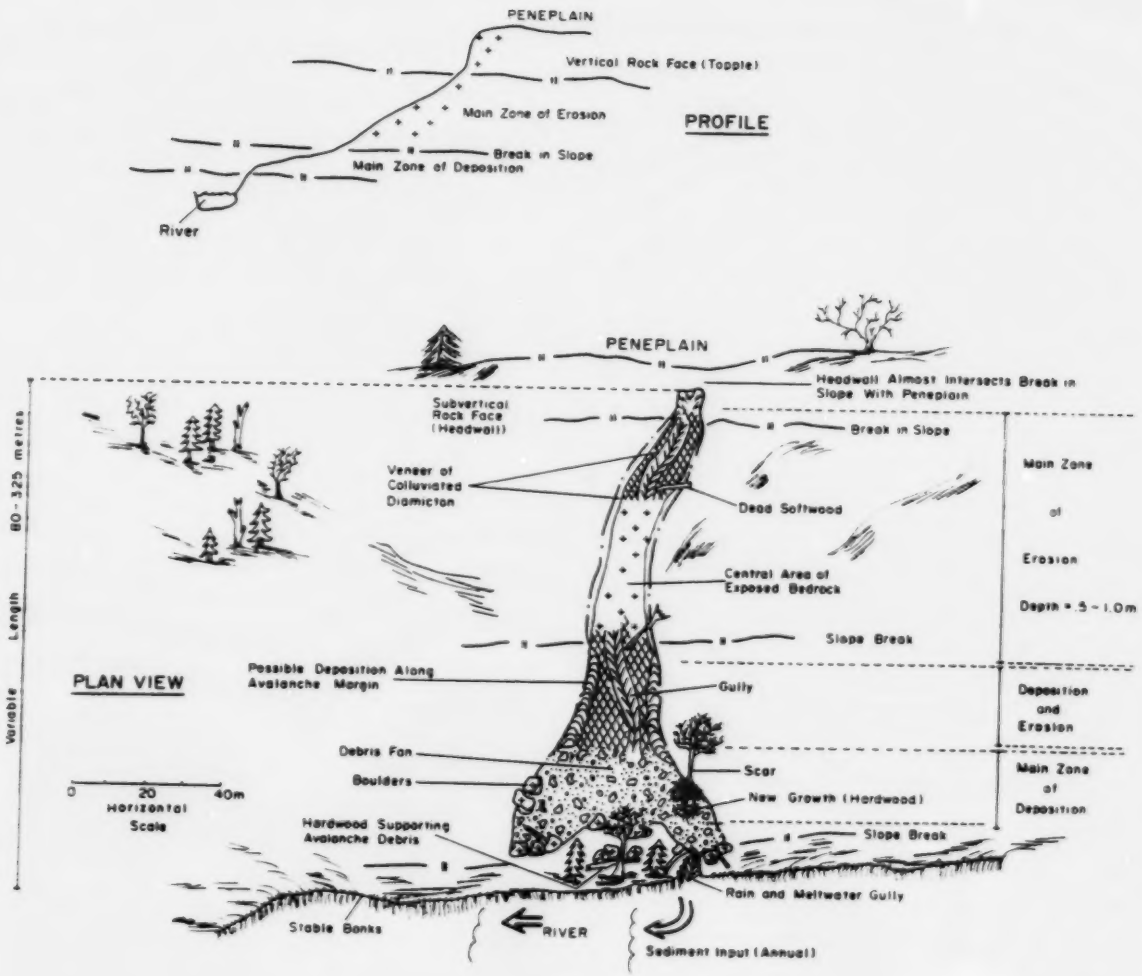


Figure 11. Intermediate- to high-mobility avalanche - class 3.

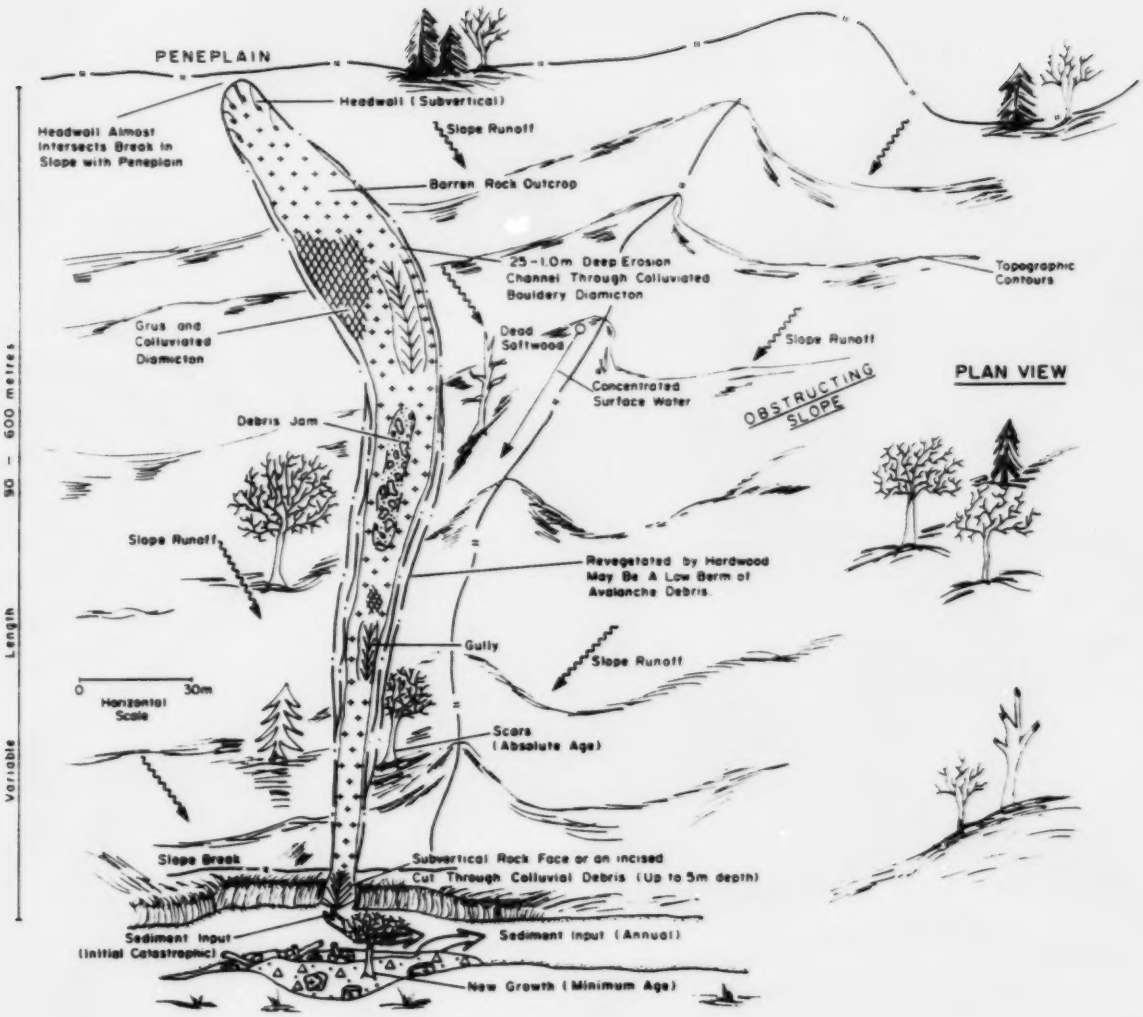


Figure 12. High-mobility avalanche - class 4.

(1991) energy is dissipated as debris hits the river and impacts on the opposite bank rather than fanning into a more open area.

Class 4 avalanches extend up-slope to intersect the regional peneplain surface. The upper limit of the avalanche consists of a subvertical headwall below which the avalanche chute is barren bedrock with the exception of minor amounts of colluviated diamicton and debris obstructed by collapsed vegetation (Figure 12). The avalanche channel narrows down slope and enters the river over a subvertical rock ledge.

High-mobility avalanches produce large volumes of debris (average = 6200 cubic metres per event; Table 1) that is input catastrophically into rivers. The debris is often sufficient to block a river for a short period of time. The author feels that the presence of boulders and large numbers of trees, e.g. avalanche site 4 (Mark Shanty Brook) is sufficient to permit water to flow through the dam preventing a total blockage of flow. This is illustrated at Peters Brook (Site 7) were the brook is blocked by avalanche debris, however the rock debris has been washed down stream so that water flow is only slightly obstructed by a jam of decaying tree trunks. In addition to the catastrophic sediment input the debris piles, e.g. Nile Brook (Site 2) serve as an annual source of sediment input. The "open" avalanche chutes also serve as an additional source of annual sediment input and in the case of multigeneration avalanches, a further source of catastrophic sediment input.

5.0 Dendrochronology

5.1 Introduction

Avalanche dating serves two main purposes. First, by constructing a time verses avalanche frequency distribution the historical record of avalanches can be examined. This allows the critical question of whether avalanches are a steady state time independent phenomena to be answered. Secondly, the shape of the time verses frequency distribution indicates what natural, anthropogenic or combination of such factors are influencing the distribution of avalanche.

To construct a time verses frequency distribution an unbiased examination of avalanches within the time period in question is critical. Bias may occur by (1) selecting a non representative subsample of avalanches within the highland area or (2) by preferentially dating recent small avalanches vs older revegetated, difficult to recognize avalanches. In this study all avalanches within the study area (n= 56) were sampled. Dendrochronology reference texts used as a guide for methodology include Cooke and Kairiukstis (1990), Schweingruber (1989) and Fritts (1976). During field investigations it was observed that most avalanches revegetate slowly. Several avalanches were partially overgrown with grass but most avalanche channels are bare rock with only minor shrubs, grass and colluviated soil, regardless of age. For example the pre-1966(67) avalanche channel at Nile Brook (#2a), after 24 years, is still bare rock. In the lower part of the avalanche chute this is a function of reactivated sliding from above during 1980. However in the upper part of the slide channel revegetation is slow due to erosion by runoff. Thus revegetation (masking of "old" avalanches by new growth) is not a significant factor.

5.2 Age Determination

Tree ring growth patterns vary depending on external stresses effecting a tree. Thus the reaction of a tree to the stress of an avalanche (ie the avalanche event) can be dated by (1) using the occurrence of damaged growth rings (scaring) and (2) by using the occurrence of reaction wood (see Glossary,

Table 2: Estimated Sample Ages, Image Ages, Revegetation Times, and Actual Ages for avalanches located in the Southern Cape Breton Highlands.

AVALANCHE SITE	ESTIMATED SPL. AGE (ESA)	IMAGE AGE (IA)	REVEGETATION TIME (RT)	ACTUAL AGE
2a	Pre-1966(67)	IA > 1975	-	Pre-1966(67)
2b	1980	1975 > IA > 1984	RT < 4	1979
4a	1925	IA > 1975	-	1925 ±
4b	1971	IA > 1975	-	1971
4c	1990	-	RT > 1	1990
6	1946	-	-	1946 ±
7	1981	1975 > IA > 1984	RT < 5	1980
9a	1991	IA < 1984	-	1991
9b	1977	1975 > IA > 1984	RT < 2	1976
	1981	1975 > IA > 1984	RT < 6	1980
9c	1984	1975 > IA > 1984	RT < 9	1983
9d	1986	IA < 1984	RT < 1	1985
9e	1984	1975 > IA < 1984	RT < 9	1983
9f	1986	IA < 1984	RT ≤ 1	1985
12	1986	- IA > 1975	- -	1986 Pre-1975
13	1960 ± 2	IA > 1975	-	1960 ± 2
14	1963	IA > 1975	-	1963
15	1985	IA < 1984	RT = 0*	1985
16	1984	1976 > IA > 1984	-	1984
17	1985	1975 > IA > 1984	RT > 10	1984
18	1985	1975 > IA > 1984 1975 > IA > 1984	- -	1985(847) 1975-1984
19	1979-1982	1975 > IA > 1984 IA > 1975	- -	1981 Pre-1975
20	1967	IA > 1975	-	1967
21	1985	IA < 1984	RT ≤ 1, 2	1985
23	1989	IA < 1984	-	1989
24	1954 ± 5	IA > 1975	-	1954 ± 5
25	1984	1975 > IA > 1984		1984
27	1980	1975 > IA > 1984	-	1980
28	1981	1975 > IA > 1984	-	1981
31	1982	1975 > IA > 1984	-	1982
32	-	1975 > IA > 1984	-	1975-1984
33	1985	1975 > IA > 1984		1984±
34	1986	IA < 1984	RT < 1	1985
35	1990(91)	IA < 1984	-	1990(91)
36	1990**	1975 > IA > 1984	-	1975-1984
38	1979-1985	1975 > IA > 1984	-	1984
39	1985	IA < 1984	-	1985
40	1981-1982	1975 > IA > 1984	-	1981-1982
41	1981	Overhanging veg.	-	1981
42	Multiple Events	IA > 1975	-	Pre-1975
43	1982	1975 > IA > 1984	RT < 7	1982
44	1990	IA < 1984	-	1990***
45	1985	IA < 1984	-	1985
46	1987	IA < 1984	-	1987
47	1986	IA < 1984	-	1986
48	1970	IA > 1975	-	1970
49	1974	IA > 1975	-	1974
50	1977	IA < 1984	-	1977(?)
51	1990	IA < 1984	-	1990
52	1974	IA > 1975	-	1974
53a	-	IA < 1984	-	Post 1984
53b	-	IA < 1984	-	Post 1984
54	1984	IA < 1984	-	Post 1984

* RT = 0; this sample was collected on a rotational slump where young vegetation was not destroyed; ie a young seedling or a seed that germinated due to removal of canopy vegetation. RT is not a true revegetation time.

** Data is unreliable due to numerous zones of compression wood.

*** Age based on preservation of dead needles on debris.

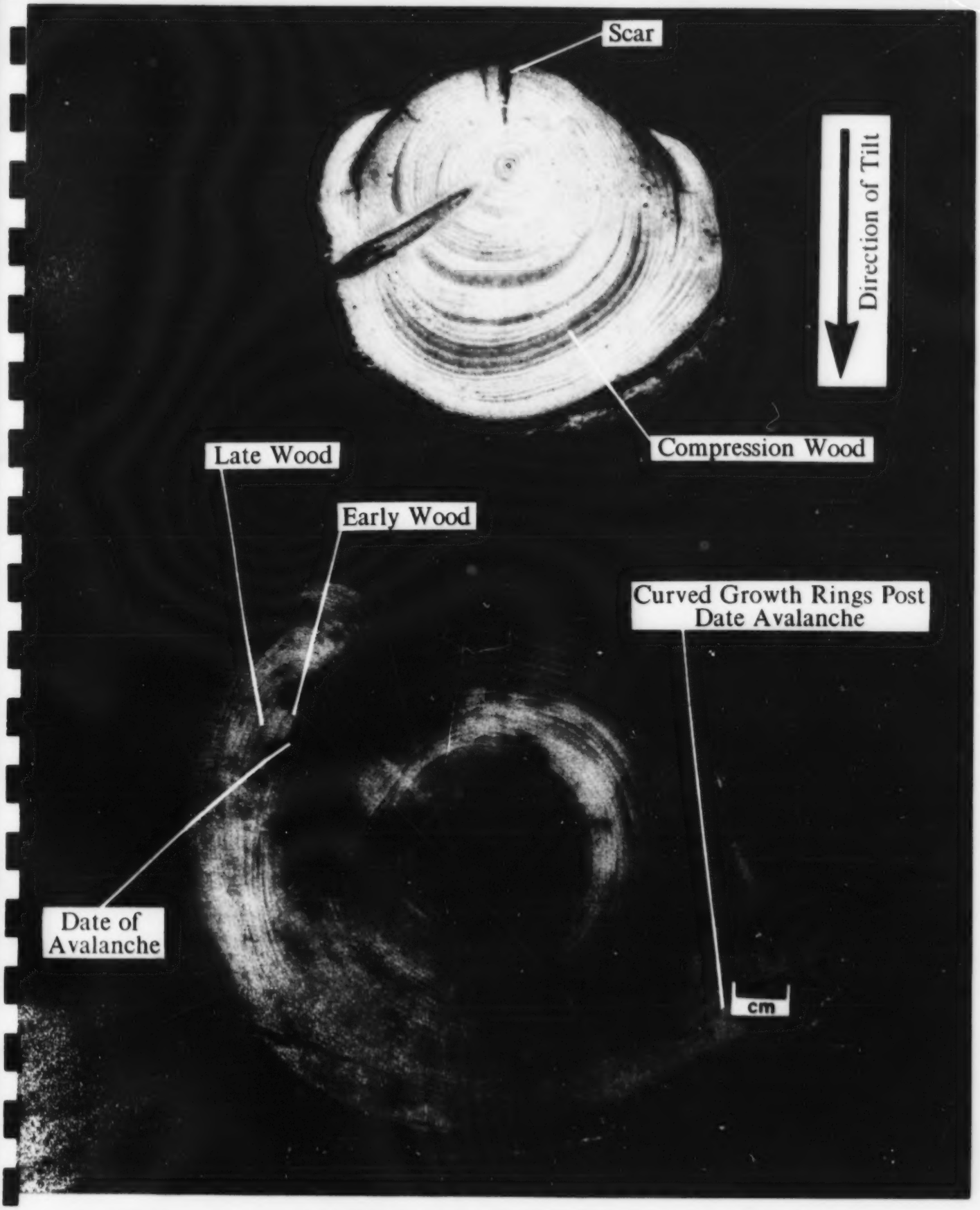
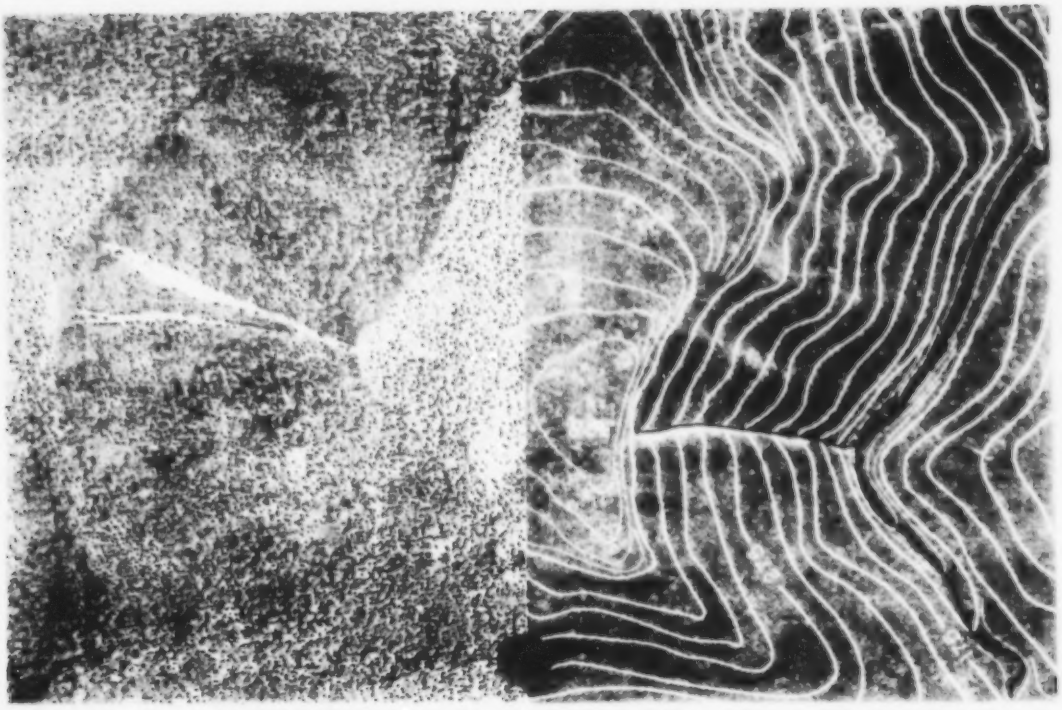


Plate 4. Typical example of growth rings, scar and compression wood used in avalanche dating.



Plates 5a and 5b. Site 2. Composite of Nile Brook on 1984 airphotographs and 1975 orthophotograph; also aerial view of avalanche taken in 1991.

Plate 6. Scar on vegetation proximal to an avalanche chute.

Appendix A) in response to tree tilt. In addition a minimum age can be determined by counting the absolute number of growth rings (each represented by a early wood - late wood couplet; see Glossary, Appendix A) present in a cross section (Plate 4) of new growth on the avalanche debris or in the avalanche chute. In this study all three of the above methods were used, either singly or in combination, in order to date each avalanche (Appendix D). Where the age of an avalanche could be bracketed based on its presence or absence on airphotographs, this relationship was used to check the accuracy of the dendrochronological age (Table 2; Plates 5a and 5b).

A scar yields an absolute age (see Glossary, Appendix A) for an avalanche event by dating the damage caused to a tree from the falling debris along the side of the slide channel (Plate 4 and 6). The avalanche must be examined carefully in order to determine if more than one avalanche event occurred. Falling rock debris loosened by the original avalanche will produce young scars that will yield a false "young" age for the avalanche, e.g. avalanche #20 (Appendix D).

Trees growing along the sides of avalanche channels typically lean toward the channel due to a loss of root support. Similarly trees disturbed by debris may be tilted. In both cases the avalanche can be accurately dated by examining the growth rings in trees reacting to tilt. The occurrence of reaction wood (see Glossary, Appendix A) corresponds to the season during which the avalanche occurred or, if the avalanche occurred while the tree was dormant, the following growing season. This method of absolute dating was successfully applied to avalanche # 16 with the occurrence of compression wood (see Glossary, Appendix A) in three sections from a fir tree (Appendix D).

Avalanches form debris fans which are revegetated by trees. A minimum age for the avalanche can be calculated by counting the number of growth rings in a section of new growth found on a debris fan. For this to be valid the oldest tree on the debris fan must be sampled, however this is not always the largest tree. It was observed that hardwoods are often larger than older soft woods. Thus representative sampling involved collecting several samples from each site as well as a lot of "on the job experience". Application of this dating method was used at avalanche 9c and 9f on the Barrachois River (Appendix D).

Several samples were usually collected from each avalanche (Appendix D), however dangerous, unstable slopes or a lack of datable material occasionally limited sampling. The ages of samples collected at each avalanche were compared, the field observations and presence of more than one avalanche event considered, and an Estimated Sample Age (ESA)(see Glossary, Appendix A) determined (Table 2). In cases were minimum ages were determined it was necessary to determine a Revegetation Time (RT)(see Glossary, Appendix A) in order to correct the ESA (Table 2).

Maximum and minimum RT's were determined by comparing the minimum ages with control ages. For example at Peters Brook (avalanche #7) the Image Age (IA, see Glossary, Appendix A) was less than 1975 and greater than 1984 (Table 2), ie the avalanche was not on the 1975 orthophotograph but was present on the 1984 airphotograph. Examination of scars within the entire data set revealed complete early wood - late wood sequences prior to avalanche events, ie the avalanches generally occur after the growth cycle while the tree is dormant (late fall to early spring). Early spring is the most likely time for slope instability due to frost heave and high soil pore pressures due to rain and snow melt. Based on these relationships the maximum RT for avalanche #7 is 5 years. Using similar relationships and assumptions for the entire data set RT was determined to be 1 year, ie one dormant - growth -dormant period. This is illustrated in Appendix D and Table 2 for avalanche #34 (Northeast Margaree River).

Actual Ages were determined for each avalanche (Table 2). The actual age is the ESA of the avalanche event corrected with respect to the RT, ie ESA - RT = actual age (see Glossary, Appendix A). The actual age of an avalanche and its ESA is the same if the ESA is based on an absolute age (a scar

or reaction wood) rather than a minimum age (a new growth section).

5.3 Time Verses Avalanche Frequency

Actual Ages from Table 2 were used to construct an avalanche time verses frequency distribution for the southern Cape Breton Highlands (Figure 14). Avalanche events for which a specific year (age) could be determined were plotted on the frequency distribution. Avalanches in which the age could only be bracketed were not plotted, e.g. avalanche #18 (1975 > IA > 1984). As such 46 ages out of a total of 56 were plotted. The age distribution of the remaining 10 are not significantly different from that of the 46 ages plotted (Figure 14) and thus would not alter the general shape of the time verses frequency distribution.

Given realistic uncertainty in the avalanche dating and sampling methodology, in conjunction with the age distribution of other avalanches on Figure 14, an increase in avalanche frequency during the time interval 1980 to 1990 is clearly indicated. Three peaks in the avalanche frequency occur between 1980 and 1990. However an error of plus or minus even 1 year would significantly flatten the distribution, with the exception of the year 1985. However, this would not alter the overall trend of increasing avalanche frequency. Prior to 1980 the avalanche distribution is scattered. The relative decrease in the frequency of avalanches with increasing age (e.g. older than 1960) as compared with the 1960 to 1979 time interval probably reflects an inherent difficulty in observing and dating the older events (revegetation, poor quality airphotographs).

Pre-1980 avalanches on Figure 14 are interpreted as representing background levels of avalanche reflecting a steady state process of mass wasting. Post- 1979 avalanches reflect a natural or anthropogenic (man made) change capable of effecting slope stability within the highland region. This change or effect does not reflect a catastrophic event (see section 6.2.5, Earthquake) but rather a long term change. This change may not coincide with the 1980 to 1990 time interval but rather the effect of this event(s) may only manifest during this time interval.

The distribution of avalanches within the study area can be described as a regional distribution of clusters. Figure 15 is a series of avalanche time verses frequency diagrams plotted by cluster or catchment basin. On a gross scale the five catchment basins have avalanche time verses frequency patterns similar to the regional distribution (Figure 14). The most obvious exception is several avalanches on Indian Brook during the early to mid-1970's. It is reasonable to conclude that slope stability is being reduced by a regional mechanism in conjunction with site specific factor(s) that are acting as the actual triggering mechanism.

6.0 Avalanche Susceptibility Assessment

6.1 Introduction

Palmquist (1983) summarized the concept of regional avalanche susceptibility factors. He stated that "landslide activity has a temporal distribution which is episodic with intervals of high activity separated by intervals of stability... resulting from varying intensity of the fundamental causes - slope oversteepening... and variations in fluid pressure resulting from climatic change." Palmquist (1983) identified earthquakes as a third fundamental cause of landslides. He felt that "over durations measured in thousands of years... it should have a more constant intensity". This report examines avalanches over a 70 year time interval, most of which occur within the last 30 years. Thus short term avalanche

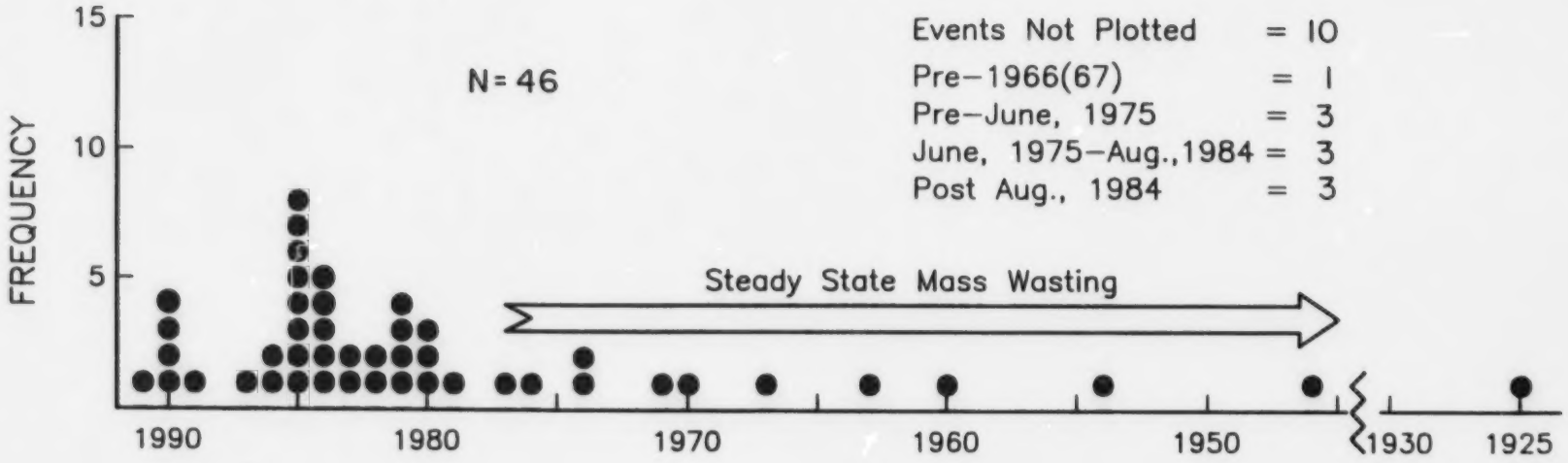


Figure 14. Time verses avalanche frequency diagram for the southern Cape Breton Highlands, 1925 - 1991.

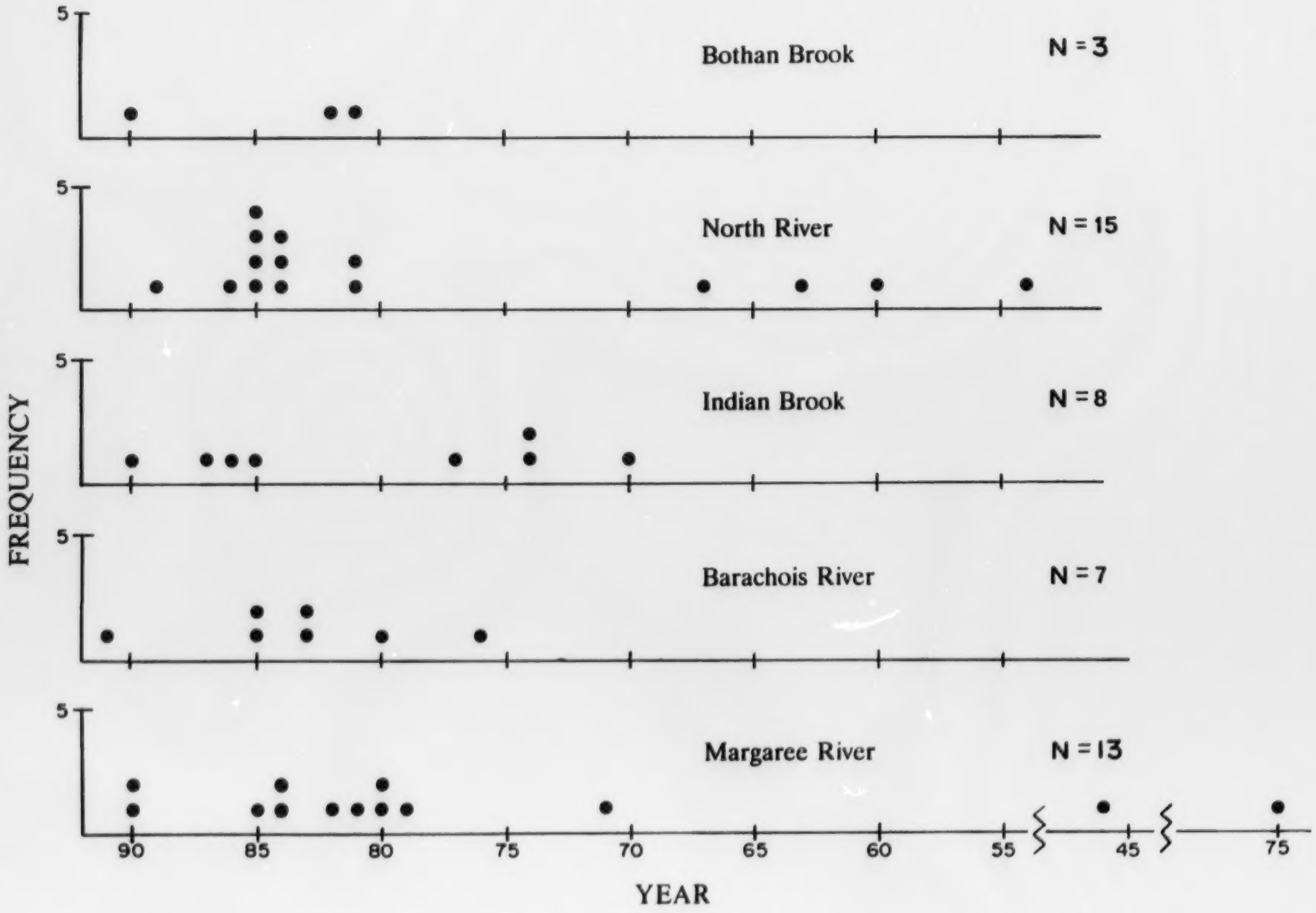


Figure 15. Time verses avalanche frequency diagram for the southern Cape Breton Highlands (plotted by catchment basin), 1925 - 1991.

triggering mechanisms are much more important than long term causes of slope instability when assessing avalanche hazard within the study area.

6.2 Avalanche Triggering Mechanisms

A main purpose of this report is to identify natural or anthropogenic events that combine with the fundamental causes of slope instability and act as triggering mechanisms of avalanche. The trigger causes an unstable slope to fail; it is the immediate cause of an individual landslide but it is not the cause of the slope instability (Palmquist, 1983). Several possible trigger mechanisms warrant consideration including road construction, forest harvest operations, budworm defoliation, extreme or changing precipitation patterns and earthquakes.

6.2.1 Road construction

A forest engineering analysis of landslides in logged areas on the Queen Charlotte Islands, British Columbia by Krag, Sauder and Wellburn (1986) identified road construction as a major factor in landslides. The failure mechanisms identified included overloading of steep slopes, road drainage onto fill slopes, altering natural slope drainage patterns and undercutting of steep slopes.

On the Queen Charlotte Islands logging and road construction was carried out on steep slopes. In the Cape Breton Highlands roads are located on the peneplain surface and cross topography at drainage divides. The large well developed road system has no interaction with valley walls. During road construction blasting was unnecessary due to the flat topography and abundant residual materials.

6.2.2 Forest harvesting

Krag, et al. (1986) identified yarding disturbances such as pulled stumps, scraping and gouging of topographic highs, tree root deterioration and windthrow as factors associated with an increase in the incidence of avalanche. The disturbances are significant only where topography is a factor. Within the study area the Northern Tableland is deeply incised by steep walled stream valleys (average slope = 40 degrees in areas of avalanches) thus restricting harvest operations to the peneplain surface. Harvesting is separated from the non-logged valley walls by green belts in excess of 100 metres wide. These belts contain well rooted hardwood that minimize windthrow along the edge of the cut blocks.

Table 3 shows the presence or absence and age of harvest operations spatially associated with avalanche sites. Avalanches which are younger than the clear cut may have been triggered by effects from the harvesting. However, in many instances avalanches are older than the harvest operations and thus no cause - effect relationship is established. For areas where avalanches are both spatially and temporally associated with harvest operations, removal of vegetation will decrease evapotranspiration and possibly increase the amount of run off and/or groundwater flow to the valley walls. This would increase the pore pressure in the unconsolidated materials which, historically, has been shown to be a prime factor in the sliding mechanism on aggregate slopes (Swanston, 1970).

The Inland Waters Directorate Water Resources Branch of Environment Canada maintains a monitoring station and measures river discharge on the Northeast Margaree River (Station No. 01FB001, Lat. 46 22 10 N and Long. 60 58 36 W). The Atmospheric Environment Service of Environment Canada also maintains a network of precipitation monitoring stations in Atlantic Canada, one being located at Margaree Forks. To determine if logging in the Margaree River catchment has increased discharge on an annual basis relative to precipitation (ie, decreased evapotranspiration and increased runoff relative to

Table 3. Age of harvest operations spatially and/or temporally associated with avalanche sites in the study area.

Harvest Ages (based on airphoto & field mapping)					
Avalanche Site #	Avalanche Actual Age	Pre-June, 1975	Pre-August 1984	Post August, 1984	Possible harvest influence
2a	Pre-1966(67)	-	-	-	no
2b	1979	-	-	-	no
4a	1925 ±	*	-	-	no
4b	1971	*	-	-	uncertain
4c	1990	*	*	-	yes
6	1946 ±	-	*	-	no
7	1980	-	-	-	uncertain
9a	1991	-	-	-	no
9b	1976 & 1980	-	-	-	no
9c	1983	-	-	-	no
9d	1985	-	-	-	no
9e	1983	-	-	-	no
9f	1985	-	*	*	uncertain
12	Pre-1975 & 1986	-	*	-	yes (for 1986)
13	1960 ± 2	-	*	-	no
14	1963	-	*	-	no
15	1985	-	*	-	yes
16	1984	-	*	-	yes
17	1984	-	*	-	yes
18	1975-1984 & 1985	-	*	-	yes (for 1985)
19	Pre-1975 & 1981	-	*	-	uncertain (for 1981)
20	1967	-	*	-	no
21	1985	-	*	-	yes
23	1989	-	*	-	yes
24	1954 ± 5	-	-	-	no
25	1984	*	-	-	yes
26	-	*	-	-	na
27	1980	*	*	-	yes
28	1981	-	*	-	uncertain
31	1982	-	*	-	uncertain
32	1975-1984	-	-	-	no
33	1975-1984 & 1985	-	-	unknown	?
34	1985	-	-	unknown	?
35	1990(91)	-	-	unknown	?
36	1975-1984	-	*	unknown	?
37	na	-	*(1)	*	na
38	1984	-	*(1)	*	yes
39	1985	-	*(1)	*	yes
40	1981-1982	-	*(1)	*	yes
41	1981	-	-	-	uncertain
42	Multiple Ages	-	-	-	no
43	1982	-	*	-	no
44	1990	-	-	-	yes
45	1985	-	-	-	no
46	1987	-	-	-	no
47	1986	-	-	-	no
48	1970	-	-	-	no
49	1974	-	-	-	no
50	1977	-	-	-	no
51	1990	-	-	-	no
52	1974	-	-	-	no
53	Post 1984	-	-	-	yes
54	Post 1984	-	*	-	no

na = not applicable; (1) = distance between avalanche and harvesting makes any relation to harvesting very unlikely; * indicates applicable harvest age

base flow), total discharge was normalized against total precipitation and plotted as a percentage difference, either plus or minus (Figure 16).

It is important to point out that for the Margaree River there appears to be more water coming out of the catchment basin than can be accounted for by rainfall (Figure 16). Both the river discharge and precipitation monitoring stations are located in the Margaree Valley. Much of the Margaree catchment is within the peneplain and therefore receives higher levels of precipitation than the valley area. The discharge data reflects this discrepancy. For the purpose of this comparison the absolute amount of precipitation is not important, only changes in the relative amounts compared with variations in discharge.

Harvest operations in the Margaree catchment were concentrated in the early 1970's to early 1980's (Table 3). Figure 16 shows wildly fluctuating levels of dis./precip. with the highest and lowest values occurring in the 1970 to 1980 period. A correlation of increased discharge/precipitation with avalanche frequency on a annual basis is not supported by the data (Figure 16). Similarly, no correlation exists between annual precipitation, discharge and avalanche frequency.

6.2.3 Precipitation

Extreme or changing precipitation patterns may initiate slope failure by increasing the pore pressure in slope materials. This potential trigger mechanism was examined by plotting total yearly precipitation levels at Margaree Forks for the period of record, 1960 to 1989 (Figure 17). Unusually high levels of precipitation during the 1980's as compared with the 1970's would be a possible explanation of the increase in avalanche frequency from 1980 to 1990, over that of the 1970's (Figure 14). Total yearly precipitation levels are highly erratic (Figure 17) so a five year running average was calculated to smooth the data. The highest yearly precipitation levels occurred in the early 1970's. Therefore increased precipitation on a yearly scale does not correlate with an increase in the frequency of avalanche within the study area (Figure 14).

A plot of average total monthly precipitation (ATMP) for two time intervals, 1961 - 1979 and 1980 - 1989 (Figure 18) was constructed to determine if short term variations in precipitation correlate with observed avalanche frequency. Between 1980 - 1989, during the months of April, June and November, ATMP was significantly higher than corresponding 1961 - 1979 levels. Between 1961 - 1979, during the months of May, July, October and December ATMP was significantly higher than corresponding 1980 - 1989 levels. In section 5.2 (Age determination) observation of complete early-late wood growth ring sequences indicated that avalanches occurred after the annual growth cycle, ie late fall to early spring. Thus June, July and May are unlikely months in which unusually large amounts of precipitation could have triggered these avalanches. October, November and December cannot be ruled out on the basis of growth ring evidence, however sediment is usually more stable in the fall with respect to failure than during the early spring (April) when frost thaw typically leaves slopes relatively unstable. The data suggests that high levels of total average precipitation in April during the time period 1980 to 1989 may be a factor in the observed increase in the frequency of avalanche during the same time period (Figures 14 and 15).

A plot of average cumulative monthly discharge (Figure 19) supports this conclusion. The plot shows unusually high levels of river discharge in April during the 1980 - 1990 time interval as compared with levels between 1917 - 1979; the correlation between river discharge and precipitation (Figure 18) being obvious. Unusually high levels of discharge occur in May during the time interval 1917 - 1979, again similar to precipitation trends (Figure 18). Except for April and May average monthly discharges during the two time intervals are similar.

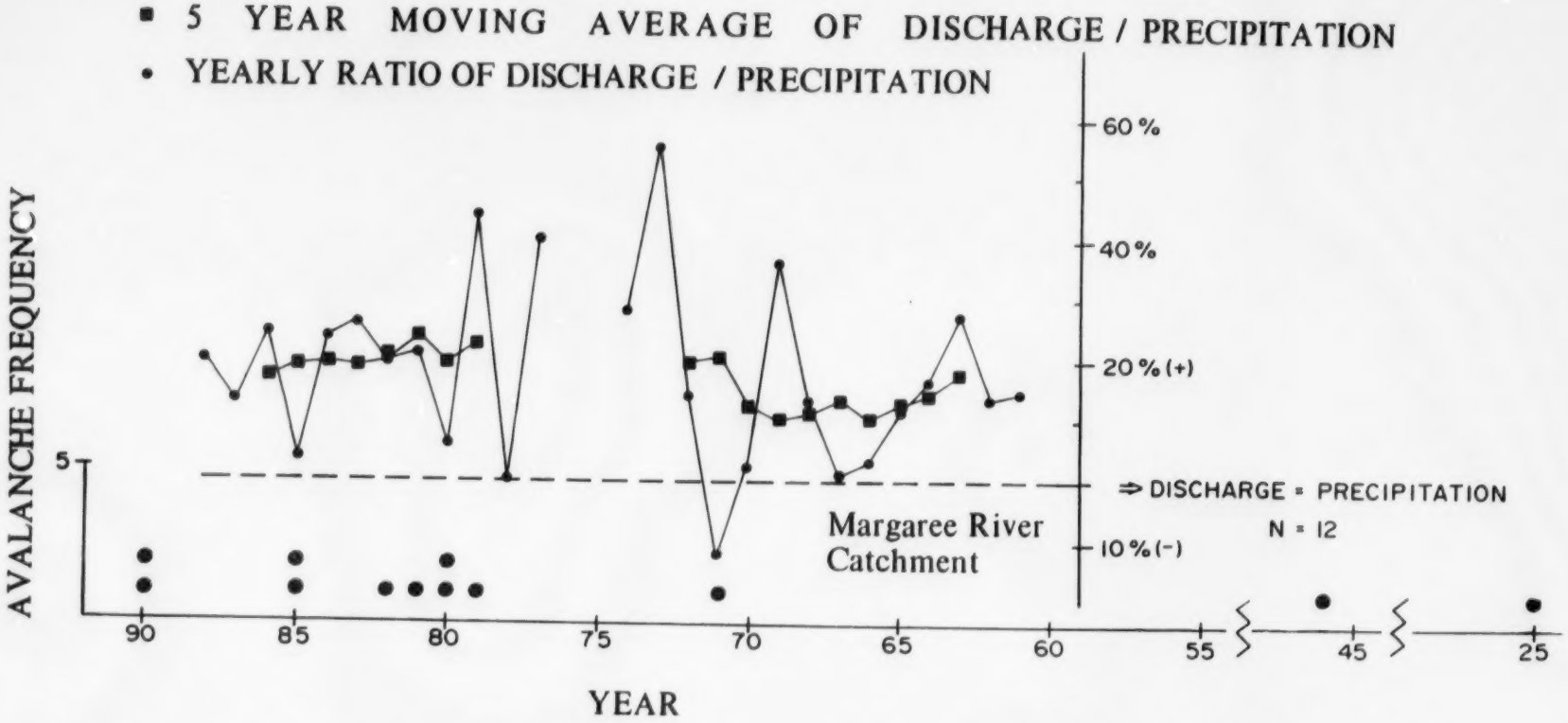


Figure 16. Total annual discharge divided by total annual precipitation for the Margaree River, plotted over avalanche frequency for the Margaree River catchment.

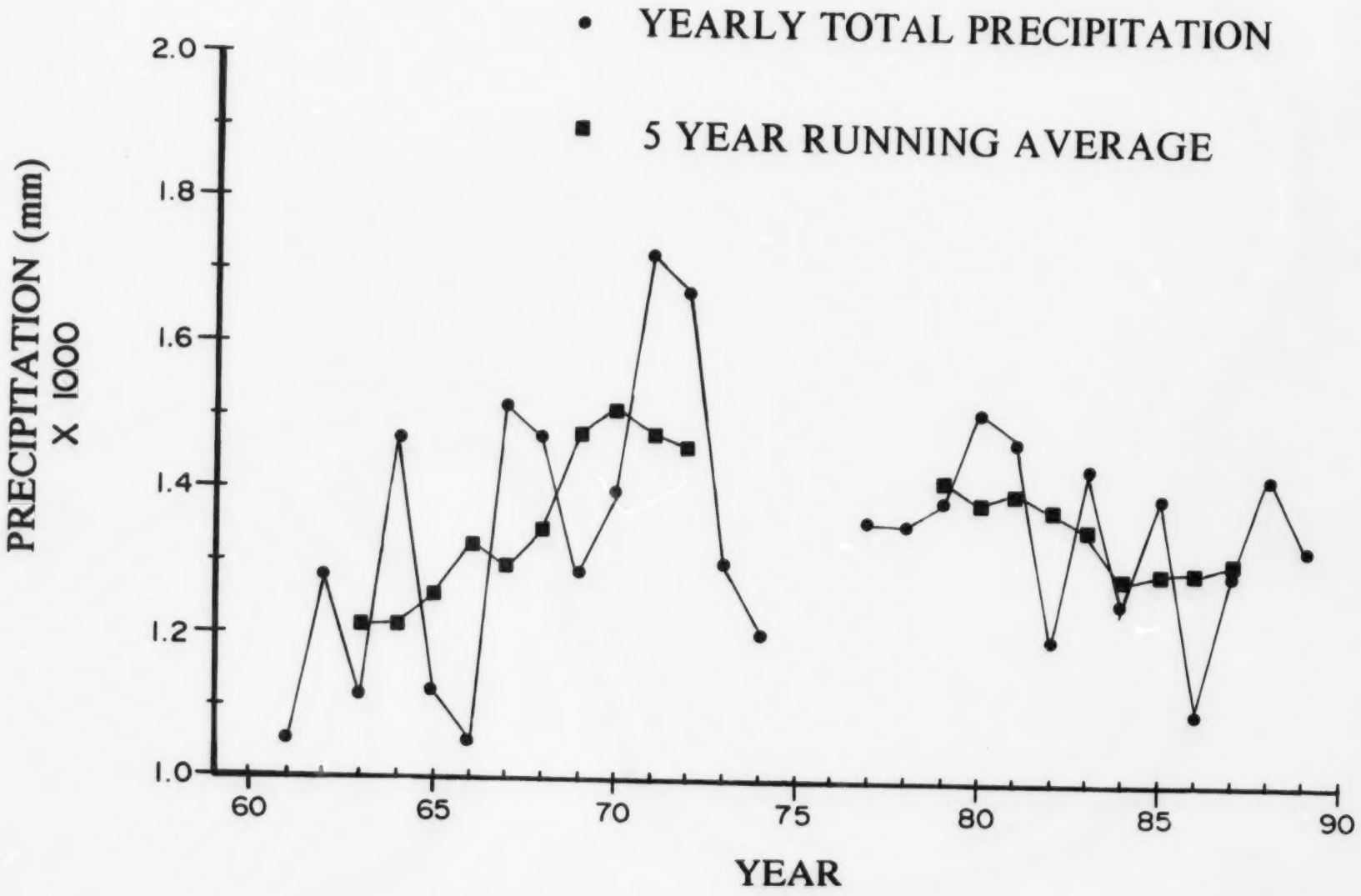


Figure 17. Total yearly precipitation (1960 to 1989), Northeast Margaree.

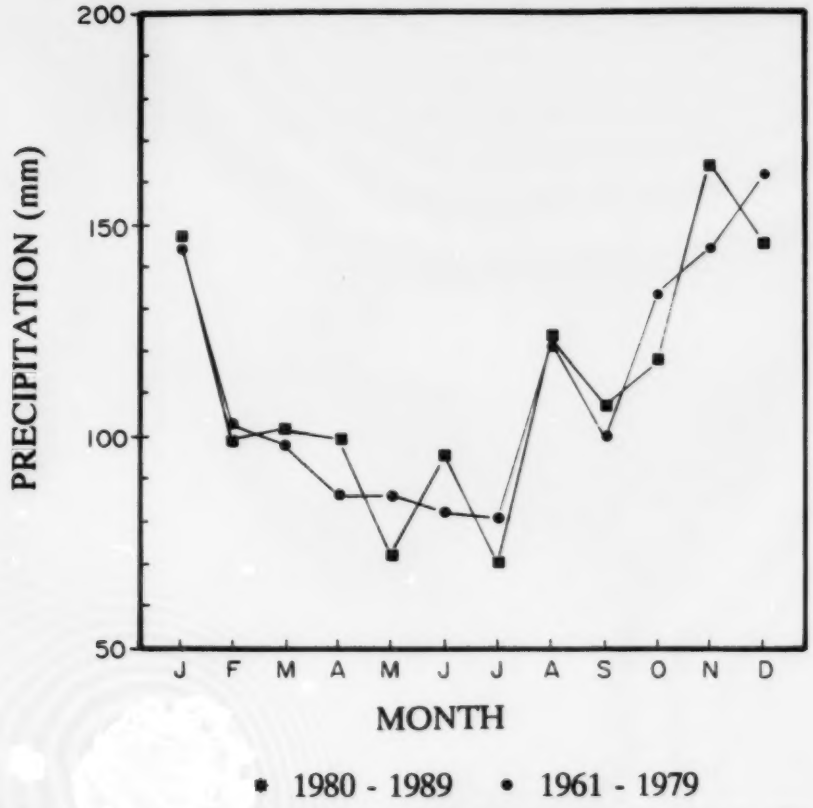


Figure 18. Average total monthly precipitation for the time periods 1961 - 1979 and 1980 - 1989 (Margaree River monitoring station).

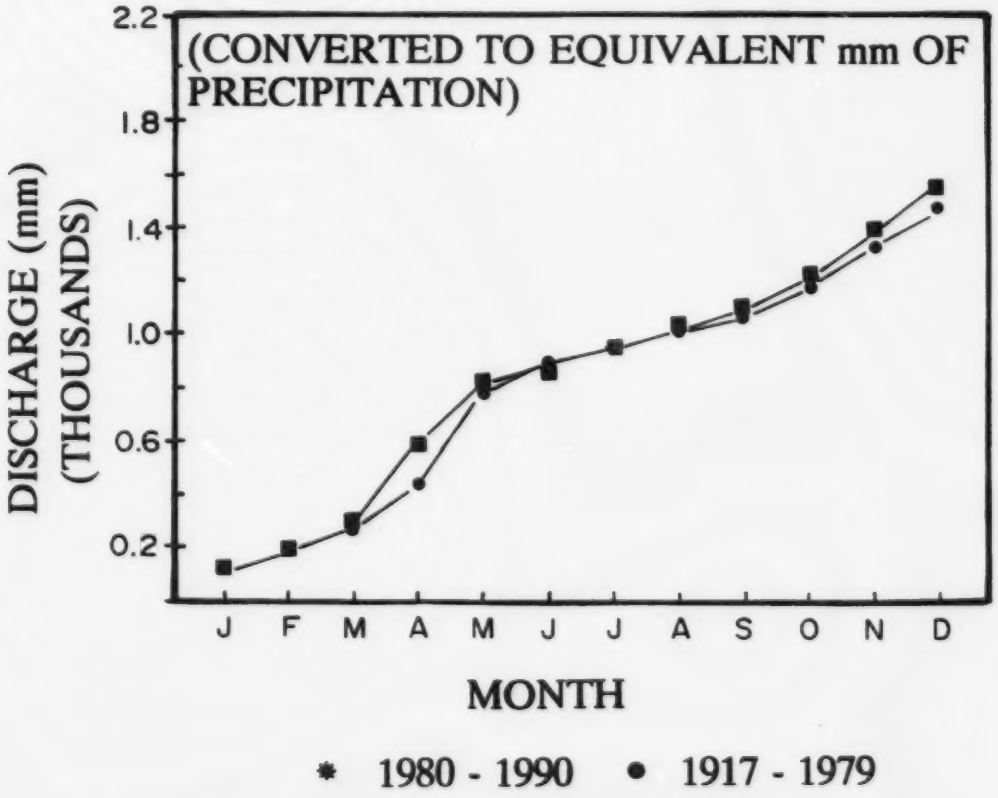


Figure 19. Average cumulative monthly discharge for the time periods 1917 - 1979 and 1980 - 1990 (Northeast Margaree River at Margaree Valley).

6.2.4 Budworm defoliation

The outbreak of spruce budworm was recognized in Cape breton by 1974 and by 1976 tree stands had already begun to die (A. Hanam, pers. comm., 1992). In section 3.4 a strong spatial association was demonstrated between dead softwood and the occurrence of avalanches. Krag, et al. (1986) and Ziemer, et al. (1977) recognized root deterioration as a prime cause of slope instability and avalanche. Death of a softwood by budworm attack with associated root deterioration is no different than "death by power saw". The death of softwood due to budworm attack on high angle critical slopes that are stable only due to the presence of vegetation support (sections 3.3 and 4.2.3) is a prime factor in creating slope instability within the study area.

Growth ring patterns in samples prior to scaring events supports this theory. Slow growth (several narrow rings) were noted in some samples (Appendix D) immediately preceding the scaring (avalanche) event. This "could" be interpreted as a prolonged drought or competition for sunlight by other trees. However, due to the spatial and temporal relation to an avalanche event a much more plausible explanation is that slow growth was in response to stress on the trees root system. As surrounding softwood died and root systems gradually decayed over a several year time span slow movement was initiated on the slope, immediately preceding the avalanche. Alternatively or as part of the same process the narrow growth rings could reflect the stress on a tree of of budworm feeding over a several year period (A. Hanam, pers. comm., 1992)

Budworm attack is a variable process, varying in severity of attack, timing of attack, abundance of soft wood and rate of death. Therefore avalanche frequency should reflect this with a distribution distributed over a time interval of several years (see Figure 14) rather than as catastrophic peaks in occurrence. Thus budworm damage as a prime trigger mechanism agrees well with the shape of the avalanche time frequency diagram.

6.2.5 Earthquake

Within the 70 year time frame of this study and specifically within the time interval 1960 to 1991 the frequency of earthquakes is sporadic (Table 4). Earthquakes are regional catastrophic events that should produce spikes in the avalanche frequency diagram followed by a rapid drop off in frequency to background. In this case earthquakes are a trigger mechanism of avalanche rather than a long term cause of slope instability, contrary to Palmquist (1983).

Table 4: Time distribution of earthquakes in Eastern Canada (modified from Locat and Chagnon, 1989).

Date	Epicentre	Intensity	Magnitude
1534-1535	Les Eboulements	IX-X	
June 1638	St. Lawrence Valley	Lx	
Feb. 1663	La Malbaie	X	
Sept. 1732	Montreal	VIII	5.6-6.0
Dec. 1791	Baie-St.-Paul	VIII	
Oct. 1860	Riviere-Ouelle	VIII-Lx	

Oct. 1870	Baie-St.-Paul	Lx	
28 Feb. 1925	La Malbaie	Lx	
18 Nov. 1929	Grand Banks		7
9 Jan. 1982	Miramichi		5.7

There were only two significant earthquakes in the region during the study period and only one (1982) during the time period 1980 to 1990. Figure 14 shows that the increase in the incidence of avalanche occurs as a continuum over a ten year period rather than as isolated spikes representative of catastrophic events. The January, 1982 earthquake occurred during a dormant growth period agreeing with dendrochronologic evidence. However earthquakes do not explain the occurrence of narrow growth rings (section 6.2.4) immediately preceding avalanche events.

6.3 Future Risk

In order to accurately assess future risk of avalanche, areas that were historically prone to avalanche are identified. Thus, areas where avalanches may be reactivated are identified, but more importantly, local and regional factors leading to slope instability can be determined by using the historic avalanches as case studies. Based on this information a flow chart or check list can be constructed to establish the relative degree of avalanche hazard for an area. As Cooke and Doornkamp (1990) point out, any such scheme must be qualitative rather than quantitative since the significance of a particular value depends on its local context.

Table 5 depicts the relationship between the incidence of debris avalanche and variations in factors controlling slope stability that appeared significant in this study. In addition, several critical factors that may effect slope stability when present (marked with an astrix) but not observed within the study area are included.

FACTOR	Decrease <------ **INCIDENCE OF DEBRIS AVALANCHE** ------>		Increase
<u>Slope Characteristics</u>			
Bedrock competence	Low	Moderate	High
Slope angle	Low	Moderate	High
Dip of joint or fault	Low	Moderate	High
*Direction of dip (with respect to slope)	Away	Normal	Towards
Valley-side shape (parallel to contours)	Spur	Straight	Cove
Change in valley-side gradient (in section)	Constant	Middle slope	Upper slope

Rock topple	Absent	Present/base	Present/top
Presence of minor slope failures	Absent	Present/base	Present/top
<u>Vegetation</u>			
Type	Hardwood	Mixedwood	Softwood
Amount of dead softwood or dead trees in general	Low	Moderate	High
Growth distribution of hardwood - softwood	Homogenous	Variable	Heterogeneous
<u>Hydrologic Conditions</u>			
Presence of factors that may lead to an increase in pore pressure	No		Yes
Permeable over impermeable soil/bedrock stratigraphy	No		Yes
<u>Precipitation patterns</u>			
Unusually large amounts of precipitation	No		Yes
Timing	Summer	Winter / Fall	Spring
<u>Anthropogenic factors</u>			
*Tree harvest on slope	No	Proximal(?)	Yes
*Tremors (natural or man made)	No	Minor	Severe

Note: This table is modelled after Cooke and Doornkamp (1990).

It is beyond the scope of this project to construct a hazard map for the highland region. However, if site specific avalanche triggering mechanisms identified in this paper are combined with general factors affecting slope stability, such maps could be readily constructed at scales of 1:50 000 or smaller.

7.0 Summary and Conclusions

7.1 Summary

The Northern Tableland is a dissected peneplain overlain by thin residual materials (saprolite, grus and felsenmeer) in the west and variable thicknesses of allochthonous and autochthonous till in the east. The author examined 49 avalanche sites within the study area. The 55 avalanche events at these sites were classified as: (1) low-mobility, (2) intermediate-mobility, (3) intermediate- to high-mobility and (4) high-mobility avalanches. The debris avalanche classes are characterized as follows:

(1) Low-mobility avalanches develope at the base of slopes where undercutting, high slope angle, root deterioration and loss of soil strength are triggering mechanism. These are low volume avalanches (avg. = 210 cubic metres of debris) with initial catastrophic stream/river sediment input and secondary minor annual input.

(2) Intermediate-mobility avalanches develope on the upper, middle and lower slopes of straight and gently curving valley walls due to a high slope coupled with rock topple due to increased levels of precipitation and loss of soil strength from root deterioration. Initial failure is at the diamicton-rock interface on the middle- to upper-slope area or within thick till plastered along the valley wall. Avalanches developed in diamicton catastrophically input an average of 700 cubic metres of debris per event while avalanches in the till input (catastrophically and annually) a total average volume of 5150 cubic metres of debris.

(3) Intermediate-to-high-mobility avalanches initiate on the middle- to upper-valley slope and extend to a lower-slope where the gradient is insufficient to maintain movement. Failure is at the diamicton-rock interface and is caused by mechanisms described above. These avalanches produce on average 3500 cubic metres of debris. However much of the debris is stored, at least temporarily, on the valley wall.

(4) High-mobility avalanches extend up-slope to intersect the regional peneplain. Failure is between the diamicton-rock interface on the middle- to upper-slopes by the mechanisms outlined above. On average 6200 cubic metres of debris is catastrophically input into rivers, often temporarily blocking the river.

Dendromorphological evidence indicates that the frequency of debris avalanche has increased significantly since 1980. Seventeen avalanches have ages between 1925 and 1979 while 34 avalanches have ages between 1980 and 1991. Avalanches are distributed regionally across the study area. Superimposed on this regional distribution are local clusters within 5 catchment basins. This indicates that valley walls are regionally unstable due to slope oversteepening, however local factors or triggers are controlling the site specific avalanche distribution.

Several potential avalanche trigger mechanisms are discussed in this study. These include road construction, ground disturbance and increased runoff due to logging, unusual variations in precipitation, budworm defoliation and earthquake. Due to the spatial separation of logging roads and valley walls no connection is apparent between avalanche and road construction. A correlation of ground disturbance due to logging and an increased frequency of avalanche is well documented in literature. However due to the restriction of logging to the peneplain surface no connection exists between ground disturbance and avalanche within this study area. Increased runoff to the slopes with a increase in pore pressure can trigger avalanches, however no clear relation exists between the timing of harvest operations and the occurrence of avalanches in the present study area. In April, during the time period 1980 - 1989, there is increased precipitation as compared with the time interval 1961 - 1979. This correlates with unstable ground conditions due to thaw (spring breakup) and may influence avalanche frequency. Discharge date supports this observation. Budworm defoliation is a prime cause of softwood death. Softwood mortality with the loss of root support on critical slopes is a factor in avalanche occurrence. The correlation of high softwood concentrations in avalanche debris, a spatial association of softwood with avalanche prone slopes and the shape and timing of the avalanche frequency distribution curve support the budworm defoliation-avalanche relationship. Similarly the 10 year period of increased avalanche frequency indicates that earthquake is not a factor in the occurrence of avalanches within the study area. This, because no avalanches have recently occurred in or near the highland region. A large earthquake would certainly cause many of these critical slopes to fail.

7.2 Conclusions

The following specific conclusions are based on the results of the survey.

(1) Surficial materials in the study area consist of saprolite, grus, felsenmeer and till. Debris avalanches are restricted to steep valley slopes overlain by thin shattered rock/colluviated diamicton or a thick sandy till.

(2) Debris avalanche slopes in the study area are critical with average angles of 40 degrees. Joints associated with the avalanches have an average dip of 60 degrees, suggesting highly unstable conditions.

(3) Debris avalanches are associated with local and regional concentrations of softwood (living and dead).

(4) Debris avalanches composed of till input a greater volume of debris per event into a river than a similar avalanche of shattered rock/colluviated diamicton.

(5) Failure usually occurs on the middle- to upper-slope area. Bank undercutting is not a significant factor.

(6) In excess of 100 000 cubic metres of debris was input into rivers by avalanches in the study area. Input may be catastrophic, temporarily damming a river. Annual input influences stream sediment supply and thus geochemical exploration models.

(7) The volume of debris generated and the effect on river systems generally increases from low- to high-mobility avalanches.

(8) In the time interval 1925 - 1979 there was an average of .31 avalanches/year. In the time interval 1980 - 1991 there was an average of 3.1 avalanches/year, ie a 1000% increase in frequency.

(9) Dendromorphologic evidence indicates that most avalanches occurred between autumn and late spring.

(10) Local trigger mechanisms initiate avalanches independent of the overall regional slope instability. Regional slope instability is balanced by vegetation growth on the valley walls.

(11) Budworm defoliation, root decay and the loss of soil strength is the prime local triggering mechanism of debris avalanche. This is dependent on local concentrations of softwood.

(12) Based on a cursory examination increased precipitation on a short term basis reflect variations in the frequency of avalanche. It may have contributed to slope failure during the 1980 to 1990 time interval.

(13) Long term variations in precipitation and annual variations in discharge/precipitation do not correlate with variations in the frequency of avalanche.

(14) Ground disturbance and road construction on the peneplain surface are not factors in the increased frequency of debris avalanche.

(15) Earthquake is not an avalanche trigger mechanism within the study area based on the shape of the avalanche time frequency diagram and dendromorphologic evidence. Earthquake is a potential avalanche trigger mechanism.

(16) Avalanche hazard maps can be produced for the Cape Breton Highland region with the information presently available.

8.0 Further Research

North of the Highlands National Park boundary along the Cheticamp River numerous "old and young" appearing avalanches were observed by helicopter. Further dendrochronologic analysis in this area could be used to verify the results of this study. Incidentally, the Cheticamp River is an area particularly hard hit by budworm (A. Hanam, pers. comm., 1992)

Identification of areas proximal to slopes where harvesting is taking place now (with no present day avalanches) could be used as a control on the effect harvesting has on the frequency of avalanche.

The time-frequency distribution of avalanches could be monitored by examining airphotographs each time the area is reflown.

Within the study area large volumes of debris was input into rivers by debris avalanches, sometimes completely damming a river. Further research by other qualified personnel, if not already undertaken, on the effects this debris input might have on salmon populations (spawning) could be significant.

The effect point source input of sediment from avalanches has on stream geochemical patterns and exploration models is important from a mineral resource point of view. Possible effects such as anomaly dilution and enhancement should be further examined and quantified. A suitable area for such a study would be the West Branch of Indian Brook.

The occurrence and thickness of saprolite within the Highland area is not fully documented. Potential may exist for supergene or "lateritic style enrichment" of gold in deep residual soils, especially where these soils might be preserved by a overlying protective till blanket. This is a possible exploration model or target.

The examination of precipitation and discharge data with respect to the time distribution of avalanches in the Cape Breton Highlands is cursory in this report. More detailed analysis of precipitation, river discharge and temperature variations during the 1980 - 1990 time interval as compared with previous years is warranted. This is particularly interesting in light of the recent attention focused on "climate change". Avalanches may be a "sensitive" indicator of climate change when slope conditions are suitably modified by other natural processes.

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11.0 APPENDIX A

GLOSSARY

Absolute Age. The age of a event to which no correction factor is applied, e.g. the age of a scar represents the exact age of the event (debris impact) that caused the scarring.

Actual Age. The Estimated Sample Age of the avalanche event corrected with respect to the revegetation time. Actual Age and Estimated Sample age may be the same if the Estimated Sample Age was based on scars and reaction wood rather than sections.

Allochthonous. A deposit that is predominantly composed of material derived from external sources outside of its present area of deposition.

Anthropogenic. Refers to the direct or indirect result of mans influence.

Autochthonous. Refers to a deposit that is predominantly composed of material derived from sources proximal to its present area of deposition.

Colluvium. A loose, heterogeneous mass of soil and/or rock debris deposited by rainwash, sheetwash and/or creep.

Compression wood. Reaction wood in conifers that occurs on the lower side of the tree, is denser than normal and has a characteristic dark coloration.

Debris Avalanche. A complex failure involving components of rockfall, topple, rotational slippage, translational sliding and flow. Slope material is a till or a colluviated bouldery diamicton. The rate of movement is 1 to 100 feet per second.

Dendrochronology. The use of tree rings to date events. In this study the events being dated are avalanches, a geomorphic process of mass wasting. As such dendrogeomorphology is the actual application of dendrochronology that is being under-taken in this study.

Diamicton. A nonlithified, non sorted or poorly sorted, non calcareous, terrigenous material that contains a wide range of particle sizes.

Early wood. Large, thin walled cells formed during the early part of a trees growth cycle.

Estimated Sample Age (ESA). The estimated age of an avalanche determined by considering the various "sample ages".

Felsenmeer. A thin accumulation of usually angular blocks (may be allochthonous or autochthonous) with no fine grain sizes in the upper part, over solid or weathered bedrock (Glossary of Geology, 1980). Angular blocks or rock fragments form through the forces exerted by monomolecular films of unfrozen water that spread along and propagate pre-existing cracks in rocks (Bloom, 1978; page 112). Freezing is thought to aid in the penetration of the thin films of unfrozen water into microscopic cracks.

Glaciotectonic features. Features attributed to glacial action that reflect overturning, inversion, folding

and shearing.

Growth ring. A early wood - late wood couplet usually representing one years growth.

Grus. The fragmental product of insitu granular disintegration (grain - grain crystal boundary fracture due to weathering) of granite and granitic rocks (Glossary of Geology, 1980). Hydrating grains of biotite fracture adjacent grains of quartz and feldspar (Crooke and Gillespie, 1986), resulting in disintegration of the rock.

Image Age. The time interval during which an avalanche occurred as indicated by airphotographs and orthophotographs.

Isovolumetric weathering. During weathering elements are removed from or added to the weathering profile without dilation or compaction so that a unit volume of weathered rock can be considered to have evolved from an equivalent volume of fresh rock (Gardner, et al., 1978)

Late Wood. Flattened, thick walled cells formed during the latter part of a trees annual growth cycle.

Original slope angle. Average angle of the valley wall (measured from the horizontal) prior to an avalanche event.

Paleoplain. An ancient degradational plain that is now buried beneath later deposits.

Peneplain. A surface of regional extent, low local relief, and low absolute altitude, produced by long-continued fluvial erosion.

Reaction wood. Non-symmetric growth rings formed in response to tilting.

Residual slope angle. Average angle of the valley wall in the avalanche chute (measured from the horizontal).

Revegetation Time (RT). The time in years between an avalanche event and the occurrence of new growth either along the sides of the avalanche chute or on debris at the base of the avalanche.

Sample age. The age of a individual wood sample, scar or reaction wood as it pertains to an avalanche event. Several samples at a given avalanche site may have different "sample ages".

Saprolite. A soft earthy, clay-rich residual material formed by isovolumetric weathering. Mineral forms present in the nonweathered parent bedrock are usually preserved in saprolite as pseudomorphs of the original minerals - similarly, primary structural features are preserved.

Tension wood. Reaction wood in angiosperms that occurs on the upper side of the tilted tree.

Till. An unconsolidated diamicton deposited directly by ice underneath a glacier without subsequent significant reworking by meltwater. Till consists of a heterogeneous mixture of clay, silt sand, gravel and boulders.

Unconformity. A substantial break or gap in the geologic record where a rock unit is overlain by another that is not next in stratigraphic succession.

Appendix B: General Field Observations, Part A.

AVALANCHE	BEDROCK	JOINTS			SLOPE ANGLE		SLOPE	AVALANCHE DIMENSIONS			DEBRIS	MORPHOLOGICAL
SITE	LITHOLOGY	Major	Secondary	Minor	Original	Residual	MATERIAL	Length	Width	Depth	VOLUME (m)³	CLASSIFICATION
2a	Var. foliated augen granite	215/73 SE	308/81 SW	210/84 NW	34	34	Colluviated bouldery diamicton	475(m)	30(m)	0.75(m)	10 000	4
2b	Var. foliated augen granite	215/73 SE	308/81 SW	210/84 NW	34	34	Colluviated bouldery diamicton	350	10	0.75	2 600	4
4a	Var. foliated augen granite	-	-	-	27*		Colluviated bouldery diamicton				>4 000	4
4b	Var. foliated augen granite	-	-	-	27*	U:50 L:27	Colluviated bouldery diamicton	225	10	0.75	1 600	4
6	Un.-wk. fol. bi. monzo-grnt.	-	-	-	38	42	Colluviated bouldery diamicton	10	T:4 B:8	1.5	120	1
7	Un.-wk. fol. bi. monzo-grnt.	-	-	-	T:35* B:22*	T:35* B:22*	Colluviated bouldery diamicton	150	T:10 B:25	0.5	1 800	4
9a	Granite-granodiorite	-	-	-	45	40	Colluviated bouldery diamicton	15	9	-		1
9b	Granite-granodiorite	-	-	-	32	32	Colluviated bouldery diamicton	85	6	1	500	2a
9c	Granite-granodiorite	-	-	-	38	38	Colluviated bouldery diamicton	73	12	0.75	650	2a
9d	Granite-granodiorite	-	-	-	41	41	Colluviated bouldery diamicton	73	12	0.75	650	2a
9e	Granite-granodiorite	-	-	-	34	34	Colluviated bouldery diamicton	35	12	0.75	310	2a
9f	Granite-granodiorite	-	-	-	35	35	Colluviated bouldery diamicton	75	10	0.75	560	2a
12	Med.-gr. diorite	-	-	-	-	45	Colluviated bouldery diamicton	66	15	0.85	850	2a
13	Foliated diorite	332/76 SW	204/78 NW	313/76 NE	-	45	Colluviated bouldery diamicton	85	8	1	680	3
14	Foliated diorite	270/30 S	-	-	-	44	Colluviated bouldery diamicton	100	8	1	800	3
15	C.-gr. monzogranite	276/50 SW	339/86 NE	-	38	38	Colluviated bouldery diamicton	16	10	1.5	243	1
16	C.-gr. monzogranite	327/46 SW	233/64 SE	289/60 NE	44	44	Colluviated bouldery diamicton	53	5	T:1.5 B:3.0	600	2a
17	C.-gr. L. monzogranite	260/58 S	306/35 NE	-	36	36	Colluviated bouldery diamicton	100	T:7 B:32	0.75	550	2a
18	C.-gr. L. monzogranite	314/55 NE	196/71 NW (m)	270/63 S	60	60	Rock	70	T:10 B:18	0.5	400	Rockfall
19	Undivided metasedi-mentary	321/60 NE	201/73 NW (m)	-	T:75 B:45	T:75 B:45	Colluviated bouldery diamicton + grus	95	T:5 B:30	1	1 700	2a
20	Undivided metasedi-mentary	240/57 NW	325/73 E (m)	316/34 NE	44	44	Colluviated bouldery diamicton	48	10	0.5	240	2a
21	C.-gr. L. monzogranite	302/53 NE	277/68 SW	246/77 SE	T:45 B:42	T:45 B:42	Colluviated till and rock	110	T:8 B:15	1	1 300	3
23	Weekly fol. diorite	-	-	-	30	30	Cobbly-bouldery diamicton/till	60	T:1 B:4	T:1 B:3	660	1

24	Well-fol. diorite	-	-	-	45	45	Shattered rock	140	30	0.5	2 100	Rockfall
25	C.-gr. Bi. monzogrnt	210/82 SE	335/88 NE	-	31	31	T: Shattered rock B: Bldry. diamicton	600	T:12 B:14	T:1 B:3	24 000	4
27	C.-gr. L. monzogranite	249/73 NW	315/72 SW	-	37*	37*	Weathered rock (grus)	325	12	1	3 900	3
28	C.-gr. L. monzogranite	330/76 SW	231/45 SE	-	45	45	Boulders and grus	200	30	0.75	4 500	1/Rockfall
31	C.-gr. monzogranite	306/48 NE	236/32 SE	-	T:42 B:45	T:42 B:45	Colluviated bouldery diamicton	300	T:30 B:4	T:1.5 B:2.0	12 400	3
32	C.-gr. L. monzogranite	206/71 NW	240/76 NW	-	55*	55*	Rock	210	8	0.75	1 300	1/2a
33	C.-gr. L. monzogranite	206/77 NW	312/63 SW (m)	277/75 SW	40	40	Colluviated bouldery diamicton	250	40	1.5	15 000	4
34	Highly por. monzogranite	248/72 NW	343/87 NE (m)	-	38*	38*	Colluviated bouldery diamicton	240	8	1	1 900	4
35	C.-gr. L. monzogranite	290/8 SW	-	-	55*	55*	Rock	30	12	1	360	2a
36	C.-gr. L. monzogranite	290/8 SW	-	-	40	40	Rock and Colluviated diamicton	37	10	0.5	180	2a
37	Strongly fol. diorite	-	-	-	40	45	Colluviated diamicton	6	3	0.5	9	1
38	Strongly fol. diorite	327/34 SW	277/62 S (m)	278/62 N	42	40	Colluviated diamicton	12	4	0.75	36	1/2a
39	Strongly fol. diorite	269/19 S	290/60 S (m)	330/43 NE	40	40	Shattered rock and Colluv. diamicton	12	4	0.5	24	2a
40	Strongly fol. diorite	311/027 SW	327/75SW (m)	-	45	40	Colluviated bouldery diamicton	70	12	0.75	640	2a
41	Metamorphic rock	-	-	-	45	48	Colluviated bouldery diamicton	12	T:4 B:8	T:1 B:3	200	1
42	Granite	323/79 SW	192/73 E	-	43*	43*	Fractured rock	110	8	0.25	220	2a
43	C.-gr. L. monzogranite	309/75 SW	192/70 SE (m)	350/34 W	45*	45*	Fractured rock	140	T:20 B:8	0.25	490	4
44	C.-gr. L. monzogranite	298/85 NE	202/68 SE	230/58 SE	49*	49*	Highly fractured rock	90	6	0.25	140	4
45	Nonfoliated monzogranite	228/70 NW	219/25 SE	-	54	70	Jointed rock	50	16	4	3 200	Rockfall
46	Tonalite	281/87 N	240/48 NW	-	36*	44	Shattered rock and colluviated till	190	T:15 B:25	T:1.0 B:.25	2 000	3
47	Tonalite	-	-	-	-	45	Colluviated till/ diamicton	30	10	0.75	220	1/2a
48	Tonalite	180/48 E	191/57 W (m)	136/28 W	35*	40	Till and shattered rock	140	T:15 B:3	T:3 B:2	4 700	2b
49	Metamorphic rock	-	-	-	37*	T:44 M:48	Till and shattered rock	220	T:20 M:10	T:4 M:3	8 000	2b
50	Tonalite	-	-	-	T:36* B:21*	T:45	Till	70	22	4.5	6 930	2b
51	Tonalite	-	-	-	26 (avg.)	T:45 B:40	Till and colluv. diamicton	130	8	1.5	1 000	2b
52	Granite-granodiorite	205/38 SE	-	-	43*	45	Shattered rock	90	3	1.5	400	4
53a	C.-gr. monzogranite	320/75 SW	-	347/90	40	45	Shattered and weathered rock	90	T:8 B:10	1	1 600	2a
53b	C.-gr. monzogranite	320/75 SW	-	347/90	40	52	Shattered and weathered rock	90	T:8 B:10	1	1 600	2a
54	Metamorphic rock	-	-	-	-	-	Till and colluv. diamicton	-	-	-	-	3

- ..... no observation; m ..... also major joints; * ..... calculated from orthophotograph; T ..... top; B ..... bottom; C ..... coarse; gr. ..... grained; L ..... leuco; Un.-wk. ..... Un - to weakly; Var. ..... variably; bi ..... biotite; m ..... middle

Appendix C. General Field Observations, Part B.

Avalanche Site	Forest Inventory Classification	Visual Estimate of Slope Vegetation	Presence of Debris Fan	Composition of Vegetation in Debris	Annual or Catastrophic Sediment Input	Evidence of River Daming/Constriction	Bank Undercutting	Location of Initial Failure	Presence of H_2O in Slide Channel
2a	M2C	-	Yes	-	Initial catastrophic Annual from debris fan	Initial dam Long term constriction	No	?	Trickle
2b	M2C	-	Yes	-	Initial catastrophic Annual from debris fan	Initial dam Long term constriction	No	Slippage on middle and upper slope	No
4a	H2C	-	Yes	-	Initial catastrophic Annual from debris fan	Initial dam Long term constriction	No	?	No
4b	H2C	-	Yes	-	Initial catastrophic Annual from debris fan	Partial dam Long term constriction	No	?	No
6	M3C	-	No	Na	Annual	No	?	Bank failure	No
7	M3C	-	Yes	Mixed soft/hardwood	Catastrophic	Yes	No	Slippage on middle and upper slope	No
9a	S3C	Predominantly softwood	Yes	Living softwood	Catastrophic (boulders)	Yes (minor)	No	?	No
9b	S3C	-	Na	Na	Initial catastrophic Annual from avalanche channel	-	No	?	No
9c	M2C	-	Na	Na	Catastrophic	-	No	?	No
9d	S3C	-	Na	Na	Catastrophic	-	No	?	No
9e	S3C	-	Na	Na	Catastrophic	-	No	?	No
9f	M2C	Predominantly softwood	Yes	Predominantly decomposed softwood	Catastrophic	Constriction	No	?	No
12	S3B	Mixed hardwood and softwood	Yes	100% decomposed softwood	Initial catastrophic Annual from debris fan	Constriction	No	Rock topple on middle and upper slope	No
13	S3B	Mixed hardwood and softwood	Yes	Not visible	Na	Na	Na	Slippage on middle and upper slope	No
14	S3B	-	Yes	Not visible	Na	Na	Na	Slippage on middle and upper slope	No
15	S3C	45% dead softwood 50% live softwood 5% hardwood	Yes	Not visible	Na	Na	Na	Rational slump on middle slope	No
16	M2C	50/50 living and dead mature softwood	Yes	>90% decomposed softwood	Annual, from debris fan	50% blockage	No	?	No
17	S3C	Predominantly softwood	Yes	Predominantly decomposed softwood	Initial catastrophic Minor annual	Yes 75% to 100% initial blockage	No	?	No
18	M2C	-	Yes	Predominantly hardwood	Na 3 m x 4 m x 6 m boulders	Minor constriction	?	Rock fall (basal undercut)	No
19	M2C	Mixed hardwood and softwood	Yes	-	Initial catastrophic Annual from debris fan	Partial constriction	No	Rock topple on upper slope	No
20	M2C	-	No	Na	Catastrophic	No	?	Slippage on middle and upper slope	No
21	H2C	Mixed hardwood and softwood	Yes	Mixed; decomposed softwood and hardwood	Annual	No	No	Slippage on middle slope	No
23	H2C	-	Yes	-	Annual	No	Yes	Rational slump due to undercutting	No
24	H2C	-	-	-	Minor annual	?	?	Rock topple (basal undercut)	No
25	H2C	Mixed; with dead softwood at top, hardwood along slide channel	Remenant on opposite bank	Na	Initial catastrophic Annual from avalanche chute	Yes Dammed 38 m wide river	No	Slippage on middle and upper slope	No
27	H2C	-	Yes	Not visible	Minor Annual	No	No	Slippage on middle and upper slope	No
28	H2C	-	No	Na	Initial catastrophic	No	No	Slippage on middle and upper slope	No

31	M3C	-	Yes	Not visible	Initial catastrophic Annual from avalanche channel	Boulder rapids along proximal bank	No	Slippage on upper slope	No
32	M1B	50% hardwood 25% dead softwood 25% live softwood	No	Na	Catastrophic	No	Partial cause	Slippage along slope	No
33	M2C	Dead softwood >>> living hardwood	Yes	Mostly decomposed softwood	Catastrophic and Annual	Obliterated 160 m of brook	No	Slippage in middle and upper slope	No
34	S3B	>90% dead softwood; small young hard-wood regrowth	Yes	-	Initial catastrophic Minor annual	Minor constriction	No	?	No
35	S3C	Living and dead softwood; young hardwood regrowth	Yes	Decomposed softwood	Initial catastrophic	Minor constriction	?	Slippage on upper slope	No
36	M2C	Top: predominantly dead softwood Bottom: living soft-wood	No	-	Initial catastrophic	-	Bank loading from above	Slippage on upper slope	No
37	S3C	75% dead softwood 16% live softwood 9% live hardwood	No	-	Catastrophic	-	Yes	Bank collapse	No
38	S3C	50% dead softwood 35% live softwood 15% live hardwood	No	-	Catastrophic	-	No	Slippage on middle and upper slope	No
39	S3C	35% dead softwood 40% live softwood 25% live hardwood	No	Mainly decomposed softwood	Catastrophic	-	No	Slippage on middle and upper slope	Minor
40	S3C	10% dead softwood 30% live softwood 60% live hardwood	Yes	Mainly decomposed softwood	Initial catastrophic Annual from debris fan	Yes 30% blockage	No	Slippage on middle and upper slope	No
41	H3C	-	Mostly eroded	-	Initial catastrophic Annual for several years there after	Yes; crossed small brook; 100% initial blockage	Possible	Rotational slump (basal undercutting)	No
42	S3C	50% living softwood 50% living hardwood	Yes	Large living hardwood on top of debris	Initial catastrophic Annual from debris fan	Yes; 100% initial blockage	?	Slippage on middle and upper slope	Minor
43	S3C	Top: dead softwood Bottom: living soft-wood and living hardwood	Yes	Not visible	Initial catastrophic Annual from debris fan	Yes; 100% initial blockage	?	Slippage on middle and upper slope	No
44	S3C	Mainly living and dead softwood	Yes	Softwood	Initial catastrophic Annual from debris fan	Minor	No	Slippage on upper slope	No
45	M3C	Na	Yes	Na	Initial catastrophic Minor annual from debris fan	Yes; Up to 100% initial blockage	Yes	Rock fall (bank undercutting)	No
46	M3C/H2C	Initially 50% dead softwood 50% live hardwood	Yes	Predominantly decomposed softwood	Na	Na	Na	Slippage on upper slope	No
47	S3C/M1C	-	No	-	Minor catastrophic Minor annual	No	?	?	No
48	M2C	-	Yes (small)	-	Initial catastrophic Massive annual input from till	No	No	?	No
49	M2C	-	Yes (small)	-	Initial catastrophic Massive annual input from till	No	No	?	No
50	M2C	60% living softwood 40% living hardwood	Debris fan stabilized by vegetation	-	Initial catastrophic Minor annual	No	No	?	No
51	S2C	50% dead softwood 50% live softwood Rapid hardwood revegetation	Yes	-	Annual during flood stages	No	No	Slippage on middle and upper slope	No
52	S2B	-	Yes	-	Annual	Partial on proximal bank	?	?	No
53a	S3C	Predominantly dead softwood Rapid revegetation by hardwood	Yes (small)	-	Initial catastrophic Annual from grus in avalanche channel	Minor	?	Slippage on middle and upper slope	No
53b	S3C	Predominantly dead softwood Rapid revegetation by hardwood	Yes (small)	-	Initial catastrophic Annual from grus in avalanche channel	Minor	?	Slippage on middle and upper slope	No
54	M2C	-	Yes	No	Na	Na	Na	?	No

Na .. not applicable; - .. no observation; ? .. unknown

Appendix D: Dendrochronology samples; locations, descriptions of sample type, sample ages and growth ring observations relating to dating.

Avalanche Site	Location	Sample Number	Sample Type	Sample Age	Comments
2b	Nile Brook	N-1	Section	1981	Minimum age on youngest event
		N-2	Section	1981	Minimum age on youngest event
		N-3	Section	1980	Minimum age on youngest event
		N-4	Section	1980	Minimum age on youngest event (pre-1966/67 avalanche not dated)
4a	Mark Shanty Brook	M-3	Section	1925	Tree growing vertically out of a fallen, buried log in stream bed (dates oldest avalanche)
4b	Mark Shanty Brook	M-1	Section	1976(77)	Thick last ring (no late wood); 1990/91 age uncertain
		M-2	Section	1976±1	Uncertain heart ring and indistinct 1991 ring
		M-4	Section	1974±1	Several indistinct rings
		M-5a	Section	1973	Wide early wood on last ring (predates young avalanche)
		M-5b	Section	1975	Three years symmetric growth, following 14 years assymetric growth. Thick early wood on last ring (maximum age)
		M-6	Section	1973-75	Several indistinct rings; last ring contains late wood, ie 1990(91) ring?
		M-7	Scar	1971	Moderate thicknesss of early wood on last ring
6	Peters Brook	P-2	Section	1946	Formation of reaction wood in response to tilting; maximum age
		P-3	Section	1955	Thin early wood on last ring; minimum age
		P-4	Section	1972	Thin early wood on last ring; minimum age
		P-5	Section	1958	Thin early wood on last ring; minimum age
7	Peters Brook	P-7	Section	1982	Thin early wood on last ring; minimum age
		P-8	Section	1982	Thin early wood on last ring; minimum age
		P-9	Section	1982	Thin early wood on last ring; minimum age
		P-10	Section	1981(82)	Thin early wood on last ring; minimum age
		P-11	Section	1981	Thin early wood on last ring; minimum age
		P-12	Section	1981	Thin early wood on last ring; minimum age
9a	Barachois River			1991	1990 growth is horizontal; 1991 new growth is vertical
				1991	1990 growth is horizontal; 1991 new growth is vertical

9b	Barachois River	Ba-3	Section	1978	Thin early wood on last ring; minimum age
		Ba-4	Section	1977(78)	1990 or 1991 age of last ring uncertain; minimum age
		Ba-5	Section	1982	Thin early wood on last ring; minimum age
		Ba-6	Section	1982(83)	Thick early wood on last ring with no late wood; minimum age
		Ba-7	Section	1983	Thin early wood on last ring; minimum age
		Ba-8	Section	1981	Date based on occurrence of distinct reaction wood; four years of very slow growth (thin rings) prior to dark reaction wood, next eleven years of more rapid growth (ie increased sun light)
		Ba-9	Section	1983	Thin early wood on last ring; minimum age
		Ba-10	Section	1981(82)	Moderately thick early wood on last ring; one uncertain ring, minimum age
		Ba-11	Section	1982	Moderately thick early wood on last ring; minimum age
9c	Barachois River	Ba-12	Section	1985	Thin early wood on last ring (well defined rings); minimum age
		Ba-13	Section	1984	Thin early wood on last ring (well defined rings); minimum age
		Ba-14	Section	1985	Thin early wood on last ring (well defined rings); minimum age
9d	Barachois River	Ba-15	Section	1986	Thin early wood on last ring (well defined rings); minimum age
		Ba-16	Section	1986	Thin early wood on last ring (well defined rings); minimum age
		Ba-17	Section	1986	Thin early wood on last ring (well defined rings); minimum age
9e	Barachois River	Ba-18	Section	1984	Thick early wood on last ring (well defined rings); minimum age
9f	Barachois River	Ba-19	Section	1987	Thick early wood on last ring; minimum age
		Ba-20	Section	1987	Thick early wood on last ring; minimum age
		Ba-21	Section	1986	Thick early wood on last ring; minimum age
12	Mid. Br. North R.	North-1	Scar	1986	Thin early wood on last ring; absolute age
13	Mid. Br. North R.	North-2	Section	1959-62	A few indistinct rings that may represent seasonal variations rather than yearly growth cycles

14	Mid. Br. North R.	North-3	Section	1963	Overgrown scar dating original avalanche event; absolute age?
				1968	Overgrown scar dating younger avalanche event; absolute age?
		North-4	Section	1971	1991 growth ring not developed; sample collected July 3, 1991; minimum age
		North-5	Section	1970	Thin early wood on last ring; minimum age
		North-6	Section	1973	Thin early wood on last ring; minimum age
15	Mid. Br. North R.	North-7	Section	1985	Moderately thick early wood on last ring; minimum age
		North-8	Section	1985	Moderately thick early wood on last ring; minimum age
		North-9	Section	1985	Thin early wood on last ring; minimum age
16	Mid. Br. North R.	North-10	Section	1984	Date based on first appearance of compression wood; absolute age
		North-11	Section	1984	Date based on first appearance of compression wood; absolute age
		North-12	Section	1984	Date based on first appearance of compression wood; absolute age
17	Mid. Br. North R.	North-13	Section	1985(86)	Moderately thick early wood on last ring; uncertain heart ring, minimum age
		North-14	Section	1986	Moderately thick early wood on last ring; minimum age
		North-15	Section	1985(86)	Moderately thick early wood on last ring, one uncertain ring, minimum age
18	Mid. Br. North R.	North-16a	Scar	1985	Thin early wood on last ring; rings > 7 years prior to avalanche show moderate growth, rings representing 6 years of growth prior to avalanche are very narrow, rings post dating avalanche are very wide; absolute age
		North-16b	Scar	1985	Same as North-16a; absolute age
		North 17	Scar	1985	Same as North-16a; absolute age
19	Mid. Br. North R.	North-18	Section	1982	Thin early wood on last ring; minimum age
		North-19	Section	1979	Thin early wood on last ring; minimum age
		North-20	Section	1982	Vertical branch (tree) growing from a horizontal, partially buried log; thin early wood on last ring; absolute age?
20	Mid. Br. North R.	North-22	Scar	1979	Intermediate age avalanche impact; absolute age
		North-23	Scar	1967	Old scar dating original avalanche; absolute age
		North-24	Scar	1989	Very recent shallow rock strike; absolute age

21	Mid. Br. North R.	North-25	Scar	1985	Thin early wood on last ring; absolute age
		North-26	Section	1986	Moderately thick early wood on last ring; minimum age
		North-27	Section	1987	Thin early wood on last ring; minimum age
23	Mid. Br. North R.	North-28	Scar	1989	Thin early wood on last ring; absolute age(?)
24	E. Branch North R.	North-29	Scar	1972	Moderately thick early wood on last ring; absolute age
		North-30	Scar	1963	Thin early wood on last ring; absolute age
		North-31	Scar	1948-58	Rings are very poorly developed
		North-32	Section	1954?	Rings are very poorly developed; thin early wood on last ring
25	Margaree River	MR-33	Section		Lost sample
		MR-34	Section	1985	Thick 1991 ring developed
		MR-35	Section	1984	Thick 1991 ring developed
		MR-38	Scar	1984	Moderately thick 1991 ring
27	Margaree River	MR-36	Scar	1980	Absolute age
		MR-37	Scar	1982	Absolute age
28	Margaree River	MR-39	Scar	1982	Thin early wood on last ring; absolute age
		MR-40	Scar	1986(87)	Thin early wood on last ring; several faint growth rings
		MR-41	Scar	1981(82)	Presence of 1991 growth ring uncertain
31	Margaree River	MR-42	Scar	1982	Thick early wood on 1991 ring; absolute age
		MR-43	Scar	1984(85)	One indistinct ring
		MR-44	Scar	1982	Thin early wood on 1991 ring; absolute age
33	Rocky Brook	MR-45	Scar	1985	Small slide in compound avalanche; thick 1991 early wood; absolute age
		MR-46	Scar	1985	Large slide in compound avalanche; almost complete 1991 ring; absolute age
34	N.E. Margaree River	MR-47	Section	1987	Moderately thick early wood on last ring; minimum age
		MR-48	Section	1987	Moderately thick early wood on last ring; minimum age
		No #	Section	1986	Dark coloured and indistinct 1991 ring-wood; minimum age
35	N.E. Margaree River			1990-91	Based on debris on riverbank in area with low preservation potential
36	N.E. Margaree River	MR-49	Section		Numerous zones of reaction wood; reliable date not possible

38	E. Branch North R.	NR-50	Section	1985	Vertical branch from horizontal trunk; minimum age
		NR-51	Section	1979	Section of trunk from NR-50; predates avalanche
		NR-52	Section	1985	Thick early wood on last ring; minimum age. Vertical branch from horizontal trunk; minimum age
39	E. Branch North R.	NR-54	Scar	1985	Absolute age
40	E. Branch North R.	NR-55	Scar	1986(87)	Compound avalanche, scar faces nonvegetated avalanche, indistinct scar; reaction wood predates scaring
		NR-56	Scar	1982	Distinct ring growth, oblique to vegetated avalanche; absolute age
		NR-57	Section	1982	Based on increased width of growth rings, ie removal of canopy vegetation
		NR-59a	Scar	1983	Faces vegetated avalanche, thick early wood on last ring; absolute age
		NR-59b	Scar	1981(82)	Scar faces vegetated avalanche
		NR-59c	Scar	1975	Scar faces nonvegetated avalanche?
41	Bothan Brook	8-60	Scar	1981	Thin early wood on last ring; absolute age
42	Bothan Brook	B-61	-	-	Not dated
		B-62	Scar	-	Scar area has rotted
		B-63	Scar	-	Not suitable for dating
		B-64	Scar	1986	Thick early wood on last ring
		B-65	Scar	1985(86)	Early wood on last ring
		B-66	Scar	1982	Early wood on last ring
		B-67	Scar	1984	Early wood formed on 1984 ring prior to scaring, avalanche probably occurred during late July, 1984
43	Bothan Brook	B-68	Scar	1986	Age of young recent activity; not representative of original avalanche
		B-69	Scar	1982	Age probably representative of main avalanche event
		B-70	Section	1982	Age probably representative of main avalanche event
44	Bothan Brook			1990	No scars or new growth, age based on dead needles still on debris
45	Indian Brook	I-71	Scar	1986	Thick early wood on last ring (cut Aug. 15, 1991); absolute age
		I-72	Scar	1985	Complete 1991 ring (cut Aug. 15, 1991; absolute age
46	W. Br. Indian Brk.	B-71	Scar	1987(88)	Late wood on 1991 ring; possible arrested growth on 1987 ring?

47	W. Br. Indian Brk.	B-72	Scar	1986(87)	Indistinct rings
		B-73	Scar	1983-86	Very indistinct rings
48	W. Br. Indian Brk.	B-74	Scar	1970	Age of scar with 'old' appearance
			Scar	1983	Age of a second scar from the same tree as the 1970 date
			Scar	1986	Age of scar with 'young' appearance
		B-75	Scar	1978±	Faint rings with tentative identification
			Scar	1987	Age from two scars on the same trunk
		B-76	Scar	1986±	Extremely faint rings
49	W. Br. Indian Brk.	B-77	Scar	1985±	Extremely faint rings
		B-78	Scar	1986	Damaged in early 1986, late wood forming on 1991 ring; absolute age
		B-79	Scar	1974	Oldest appearing, largest scar (1985 is a smaller scar); absolute age
		B-80	Section	1976	Minimum age due to small, faint rings; probably same age as B-79
50	W. Br. Indian Brk.	B-81	Scar	1977	Early wood on last ring; absolute age
51	W. Br. Indian Brk.	B-82	Scar	1990?	Poor sample!
52	W. Br. Indian Brk.	B-83	Scar	1974	Absolute age; old and young scars on same trunk
			Scar	1984	Absolute age; old and young scars on same trunk
			Scar	1983	Based on two scars: absolute age
53a	N.E. Margaree River				Not safe to sample
53b	N.E. Margaree River				Not safe to sample
54	W. Br. Indian Brook				Not sampled